Arnold Schwarzenegger
Governor

SUMMARY OF TECHNOLOGY TRANSFER ACTIVITIES

PIER FINAL PROJECT REPORT

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Prepared By:
Lawrence Berkeley National Laboratory

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Prepared By:
Lawrence Berkeley National Laboratory
Eleanor Lee
Berkeley, California
Contract No. 500-01-023

Prepared For:
California Energy Commission
Public Interest Energy Research (PIER) Program

Chris Scruton
Contract Manager

Ann Peterson
Building End-Use Efficiency Team Leader

Nancy Jenkins
PIER Energy Efficiency Research Office Manager

Martha Krebs, Ph.D.
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

B. B. Blevins
Executive Director

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Advancement of Electrochromic Windows: Summary of Technology Transfer Activities

Building Technologies Program, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory, Mailstop 90-3111, 1 Cyclotron Road, Berkeley, CA 94720, USA

Journal Articles[1]

- Lee, E.S., D. L. DiBartolomeo. 2002. Application issues for large-area electrochromic windows in commercial buildings. Solar Energy Materials & Solar Cells 71 (2002) 465–491. LBNL Report 45841, Lawrence Berkeley National Laboratory, Berkeley, CA.
- Lee, E.S., D.L. DiBartolomeo, F.M. Rubinstein, S.E. Selkowitz. 2004. Low-Cost Networking for Dynamic Window Systems. Energy and Buildings 36(6):503-513. LBNL-52198, Lawrence Berkeley National Laboratory, Berkeley, CA.
- Tavil, A. and E.S. Lee. 2005. The impact of overhang design on the performance of the electrochromic windows. Proceedings of the International Solar Energy Society (ISES) Solar World Congress, Orlando, Florida on August 8-12, 2005. LBNL-57020.
- Lee, E.S. and A. Tavil. 2005. An assessment of the visual comfort and energy performance of electrochromic windows with overhangs. Submitted to Building and Environment, November 3, 2005, and accepted for publication April 11, 2006. LBNL-59064, Lawrence Berkeley National Laboratory, Berkeley, CA.
- Lee, E.S., D.L. DiBartolomeo, S.E. Selkowitz. 2005. Daylighting control performance of a thin-film ceramic electrochromic window: Field study results. Energy and Buildings 38 (2006) 30-44. LBNL-54924, Lawrence Berkeley National Laboratory, Berkeley, CA.
- Lee, E.S., D.L. DiBartolomeo, J. Klems, Ph.D., M. Yazdanian, S.E. Selkowitz. 2006. Monitored Energy Performance of Electrochromic Windows Controlled for Daylight and Visual Comfort. To be presented at the ASHRAE 2006 Annual Meeting, Quebec City, Canada, June 24-28, 2006 and published in ASHRAE Transactions. LBNL-58912.
- Clear, R.D., V. Inkarojrit, E.S. Lee. 2006. Subject responses to electrochromic windows. *Submitted to Energy and Buildings February 23, 2005 and accepted for publication March 1, 2006.* LBNL-57125.

Conference Papers[2]

- Lee, E.S., S.E. Selkowitz, M.S. Levi, S.L. Blanc, E. McConahey, M. McClintock, P. Hakkarainen, N.L. Sbar, M.P. Myser. 2002. "Active Load Management with Advanced Window Wall Systems: Research and Industry Perspectives". Proceedings from the ACEEE 2002 Summer Study on Energy Efficiency in Buildings: Teaming for Efficiency, August 18-23, 2002, Asilomar, Pacific Grove, CA. Washington, D.C.: American Council for an Energy-Efficient Economy. LBNL-50855, Lawrence Berkeley National Laboratory, Berkeley, CA.

[1] All journal articles have been included as attachments to the final report.
[2] The first conference paper has been included as an attachment to the final report. The remaining are included in this attachment.

- Selkowitz, S.E., E.S. Lee, O. Aschehoug. 2003. Perspectives on Advanced Facades with Dynamic Glazings and Integrated Lighting Controls. CISBAT 2003, Innovation in Building Envelopes and Environmental Systems, International Conferences on Solar Energy in Buildings, October 8, 2003, École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland.
- Selkowitz, S.E., O. Aschehoug, E.S. Lee. 2003. Advanced Interactive Facades – Critical Elements for Future Green Buildings? Presented at GreenBuild, the annual USGBC International Conference and Expo, November 2003. LBNL-53876.
- Selkowitz, S.E., E.S. Lee. 2004. Integrating Automated Shading and Smart Glazings with Daylight Controls. International Symposium on Daylighting Buildings (IEA SHC TASK 31), Tokyo, Japan.

Popular Press Articles[3]

- Engineering News-Record, "Glass Facades Go Beyond Skin Deep", 2003.
- Builder Magazine, article on smart windows, February 2004.
- E-Source article on electrochromic windows, May 2004.*
- Berkeley Lab Currents, "Windows of Opportunity: New facility not only offers great views, but enables researchers to develop energy efficient windows", September 19, 2003. http://www.lbl.gov/Publications/Currents/Archive/Sep-19-2003.html
- Berkeley Lab Science Beat, "Internet-based control systems for building energy-efficiency", November 26, 2003. http://www.lbl.gov/Science-Articles/Archive/sb-EETD-internet-controls.html
- Glass Magazine, "Chameleon Windows: Haven't Shown Their True Colors Yet", October 2004.*
- Scientific American, "Smart Glass: Private and Cool", September 2005.*
- Energy design resources e-news, "High-Performance Glazing: Making the Most of Today's Advanced Technologies", Issue 54, March 2006. *
- Architectural Record, "Robo Buildings: Pursuing the Interactive Envelope", April 2006.*

Presentations

- Selkowitz gave the opening paper: Energy Perspectives for Switchable Chromogenic Materials. IME-5 Conference in Denver, August 5-9, 2002.
- Selkowitz moderated a Round Table discussion on demand-responsive high-performance façades at the ACEEE 2002 Summer conference, August 2002.
- Selkowitz presented results from the EC program R&D at the PG&E Glazing Seminar, San Francisco, April 23, 2003.
- Selkowitz presented results from the EC field project at Glass Processing Days, Finland, June 2003.
- Selkowitz presented latest results and gave a tour of the Windows facility to ~40 people from DOE's State Energy Advisory Board, July 10-11, 2003.
- Lee presented latest results to the Berkeley Breakfast Club, July 18, 2003.

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[3] LBNL staff were interviewed for many popular press articles, but for some, we never received a final copy of the article. For those where we did receive final copies, the article, noted with a (*) is included in this attachment or a website link is provided.

- Selkowitz gave a presentation and tour of the Windows facility to aides of Bay Area Legislators, July 29, 2003.
- Selkowitz and Lee gave a presentation and lab tour for the Mayoral Summit, September 19, 2003. The summit involved 50-60 mayors and aides from around the US. The Summit was also mentioned in Today at Berkeley Lab on 9/18/03. Acknowledgement of thanks from the San Francisco PUC.
- Selkowitz attended a DOE Energy Star windows meeting of about 100 window manufacturers in Washington DC on September 30, 2003 and discussed the current state of the electrochromic windows field test program.
- Selkowitz attended the International Energy Agency (IEA) Task 31 Daylighting meeting in Lausanne and presented a paper at the CISBAT Conference, Switzerland on dynamic window façade systems October 8, 2003. He toured the EPFL facility that is testing electrochromic glazings and met with German researchers who have been testing EC windows in Dortmund.
- Selkowitz attended a DOE roadmapping meeting in Phoenix, AZ, October 2003. Over 70 U.S.manufacturers attended the meeting. Selkowitz summarized the goals and status of the CEC-DOE electrochromic windows field test program.
- Lee gave a tour of the window testbed with the President of the Ana G. Méndez University System in San Juan, Puerto Rico, Mr. José F. Méndez and five other members of his staff, October 15, 2003.
- Lee gave a tour of the testbed facility to 35 members of the IEA Task 40 (commissioning HVAC systems), October 17, 2003.
- Met with John Durschinger, Skidmore Owings and Merrill Architects, at LBNL October 31, 2003 to discuss SOM’s latest research program and its relation to this electrochromic windows project.
- Selkowitz presented a paper at the US Green Buildings Council Conference in Pittsburg, PA in Novermber 2003, which included results from this project.
- Lee gave a tour of the testbed facility to eight members of the American Physical Society California Section and American Association of Physics Teachers Northern California/ Nevada Section, November 2003.
- A photo of the EC testbed was included in the “What the Future Holds” portion of the 2004 DOE EERE Calendar.
- A photo of the EC testbed was included in the LBNL Calendar.
- Selkowitz discussed generic issues of smart facades and integrated systems with The New York Times and several architectural firms and consultants in New York, New York, January 2004. Visited SOM in New York to review latest electrochromic results. Visited with Alliance to Save Energy staff and briefed them on progress with this project.
- Selkowitz and Lee gave an overview of our Windows and Daylighting Research at the California Energy Commission, February 5, 2004.
- Lee gave a tour of the Electrochromic Windows Facility February 5, 2004 for a Congressional staff visitor, Colin McCormick, who is on the staff of US Congressman Edward Markey. Markey is a senior member of the Energy and Commerce Committee.
- Lee gave a tour of the Electrochromic Windows Facility to a group of ~20 visitors from the China UN Industrial Development Organization, March 8, 2004.
- Selkowitz gave an overview of windows and daylighting research including a tour of the EC testbed facility to Norbert Young, President of the McGraw Hill Construction group (includes Architectural Record magazine, Engineering News Record, Dodge, Sweets, etc.), March 17, 2004.

- Selkowitz gave a presentation of LBNL advanced facades research, including early results from this EC project, at both the IEA Task 31 meeting in Tokyo, March 22-25, 2004 and at his keynote presentation at the ICBEST conference in Sydney, Australia, March 29-April 2, 2004.
- Lee gave a keynote presentation at Lightfair 2004, Las Vegas, March 29, 2004, which included the work from the EC testbed. A more detailed presentation of the EC field test work was also presented in a 1.5 hour seminar on advanced sidelighting.
- Selkowitz presented a paper on Integrated Façade Systems to the E-Source 7th Large Commercial Building Forum in San Diego to an audience of utilities and building owners, April 2004.
- Selkowitz presented an invited paper to Society of Vacuum Coaters 47th Annual Technical meeting in Dallas on Coated Glazings for Advanced Facades to an audience of glass and coating manufacturers, April 2004.
- Selkowitz presented an overview of the EC project at a meeting of the Technical Advisory Committee of the California Lighting Technology Center, Sacramento, CA, April 2004.
- Selkowitz presented an overview of the EC project and other advanced building control systems to faculty, students and facilities managers at Stanford University, April 2004.
- Selkowitz and Lee, EC Window Lab Tour for LBNL EETD Division review, May 13, 2004. Posters generated from this tour were sent to CEC.
- Selkowitz and Lee, Round table meeting at LBNL with industry and vendors, June 22, 2004, including The New York Times, GSA, and lighting control and automated shading vendors.
- Lee, panel discussion with industry and designers on dynamic façade and daylighting controls systems to the San Francisco AIA Chapter, June 29, 2004.
- Lee gave Spencer Abraham, Secretary of Energy, a tour of the Electrochromic Windows Testbed, July 7, 2004. See article: http://www.lbl.gov/Publications/Currents/Archive/Jul-09-2004.html
- LBNL's work on reflective hydrides (the next generation electrochromic window) received the prestigious R&D100 award. See article: http://www.lbl.gov/Publications/Currents/Archive/Jul-09-2004.html.
- Lee gave Kevin Carroll, Staff Director, Energy Subcommittee, US House of Representatives Committee on Science, a tour of the Electrochromic Windows Testbed in August 2004.
- Lee presented LBNL's latest research in automated façade and daylighting control systems at the IEA Task 31 Symposium held in Torino, Italy, September 21, 2004.
- Selkowitz presented LBNL's latest research on emerging smart facades systems at ACEEE Emerging Technologies Conference, San Francisco, October 14-15, 2004.
- Selkowitz presented EC R&D results at Glass Symposium, Syracuse, New York, October 21, 2004.
- Selkowitz presented EC R&D results at the Center for the Built Environment Annual Meeting, Berkeley, CA, October 25, 2004.
- Selkowitz presented EC R&D results at the SOM Building Science and Design Research Symposium, New York, NY, November 19-20, 2004.
- Selkwotz presented EC R&D results at the Center for Environmental Design Research, Invited Lecture, Berkeley, CA, November 12, 2004.
- Lee presented EC R&D results at the Illuminating Engineering Society Convention, Gold Coast, Australia, November 4-6, 2004.
- Lee presented this project's work to DOE in the DOE Windows Program Review, December 14, 2004.

- Selkowitz attended two NFRC meetings in Florida where he had an opportunity to discuss recent results of field test work, January 2005. He met with several glass and window manufacturers attending a non-residential rating meeting. SAGE Electrochromics, Inc. has been involved with NFRC to get rating protocols developed for their dynamic windows. Selkowitz participated in a strategic planning meeting of the Board of Directors.
- Lee and Selkowitz hosted Martha Krebs, CEC, at the EC windows test facility in March 2005. Martha had an opportunity to play with individual EC pane control and was informed of the capabilities of the testbed facility and nature of our research.
- Selkowitz gave a presentation that included this EC project at the Glass in Buildings conference in Bath, UK, on April 7, 2005.
- Lee and Glenn Hughes, The New York Times, gave a presentation on The New York Times daylighting and automated shade control project at the LightFair conference, April 11, 2005, in New York. EC project results were included in the presentation.
- Lee gave presentations of the EC work in the Subtask meetings of the IEA Task 31 meeting held in Berkeley, April 18-20.
- Lee presented results from EC R&D at the PG&E daylighting seminar for IEA Task 31-45 on April 21, 2005 in San Francisco.
- Lee presented results from this project at the DOE Windows Peer Review May 18, 2005.
- Lee and Glenn Hughes, NYT, gave a presentation on the AESP Lighting Conference in Albany, NY, May 25, 2005, including results from this EC R&D.
- Presentation of DOE-2 simulation results at the ISES Solar World Congress Conference in Florida, August 2005.
- Selkowitz presented results from this study at the Lux Europa conference in Berlin, September 19-21, 2005. Shared study results at the IEA Task 31 meeting in Berlin as well.
- Lee presented EC R&D to graduate student forum at the UC Berkeley Department of Mechanical Engineering, October 3, 2005.
- Lee presented results from this study at the Daylighting Symposium, Budapest, November 1, 2005.
- Lee presented results from EC R&D at the Center for the Built Environment Noon Time Seminar, UC Berkeley, November 16, 2005.
- Selkowitz presented (Lee convenor) results of this research at the USGBC Conference, Atlanta, GA, November 9, 2005.
- Selkowitz and Lee presented EC R&D results to Southern California Edison, Irwindale, January 27, 2006.
- Selkowitz presented latest in EC R&D to DOE Commercial Buildings Team, Washington DC, February 16, 2006.
- Selkowitz presented latest in EC R&D at International Glass Manufacturers Association, Indian Wells, February 24, 2006.
- Selkowitz and Lee, Seminar on Interactive Facades, LightFair 2006, Las Vegas, May 29, 2006.
- Lee, presentation of technical paper on EC project results, ASHRAE 2006 Summer meeting, Quebec City, June 24-28, 2006.

Presented at CISBAT 2003, Innovation in Building Envelopes and Environmental Systems
International Conferences on Solar Energy in Buildings, October 8, 2003,
Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland.

Perspectives on Advanced Facades with Dynamic Glazings and Integrated Lighting Controls

S.E. Selkowitz[1]; E.S. Lee[1]; O. Aschehoug[2]

1: Lawrence Berkeley National Laboratory, Building Technologies Department, U.S.A.

2: Norwegian University of Science and Technology, Trondheim, Norway

ABSTRACT

There is growing interest in North America on the subject of highly glazed building facades. The concept of a smart, interactive façade is not new – the ability of specific facade systems to work reliably and effectively is a far greater challenge. We have been exploring various dynamic façade systems with integrated lighting and HVAC over the last 10 years. These include automated blind systems as well as emerging electrochromic glazings, both with automated dimmable lighting and smart controls. More recently we have extended this work to include internet-based control of lights, blinds and glazings using low cost chips embedded in fixtures, motors, and glazing controls. As each window and lighting element becomes a node on the internet they can be controlled via the existing building energy management system either from an occupants desktop computer, an on-site facility manager or even from a remote location. Recent experience in California with disruptions in electric supply and costly peak power suggest value for such capabilities. This paper briefly summaries the state of recent work in this field, describing a new facility with three side-by-side test rooms in Berkeley to test new electrochromic window prototypes, and identifies key performance, systems integration and cost issues now being studied. The authors bring a cross section of both North American and European experience to address the many technology, design and business issues involved.

1. Introduction and Background

As we begin the 21st century, “advanced building facades” are attracting the attention of many in the building industry. We use this term broadly to refer to building skins that are highly transparent but provide the required strategies and mechanisms to provide comfortable interior work environments without excessive energy use or adverse environmental impact. The interest in North America is growing rapidly, but in general has followed a trend that seems to have had its origin or at least re-birth in Europe. Carefully designed and well executed highly glazed building facades are intended to provide plentiful daylight indoors, visual connection with the outdoors, solar energy to offset heating needs and fresh air for ventilation purposes, all in a package that makes an appropriate architectural statement and meets the aesthetic needs of the owner and design team, and at “affordable” cost. The creation of highly glazed spaces in buildings is not novel. A history of architectural interest in such spaces and the evolving technologies to produce them would stretch back 150 years to the Crystal Palace and is beyond the scope of this paper but suggests that designers and owners have struggled with the problem for some time. The difficulty in meeting these performance goals in specialized spaces within buildings such as atria and exhibit halls suggests that creating entire buildings in a glass envelope is an even more difficult task. However there are an evolving set of technologies and design strategies that make this undertaking more readily achievable now than in the past, and new technologies now under development should further facilitate these future solutions. In the current generation of design solutions, buildings with "double envelope" facades have attracted the most attention and controversy as well. There are now numerous new buildings that employ such facades and their variants. The actual performance of these systems is unclear, and the profession suffers from a lack of objective, quantifiable data on the field performance of both the design solutions and the technology. Simple observation and word-of-mouth suggests that some solutions are working well but that others do not. Distinguishing between these, and understanding the underlying causal reasons for performance differences, is the challenge.

This paper outlines some of the technical challenges that must be solved to make transparent facades an energy-efficient, environmentally sound market reality in North America and reviews recent work at Lawrence Berkeley National Laboratory (LBNL) that is intended to contribute to this international effort. The U.S. Department of Energy's (DOE) long-term goal is a new generation of "Zero Energy Buildings", buildings that use no net annual non-renewable energy. This requires minimizing all existing energy end uses for heating, cooling and lighting, and then providing the remaining energy needs with photovoltaics or other renewables. The current generation of building facades must be vastly improved to meet these challenges. Better tools, design strategies and façade technologies are intended to emerge from our research in support of these DOE goals.

2. Context and Challenge

Building performance is fundamentally characterized by change, short term and long term, anticipated and unexpected. Many aspects of building design are driven by an assessment of projected worst-case conditions and provision of a solution for those conditions. But buildings operate under a very wide range of conditions, both internally and externally. Internal environmental needs vary widely with occupant and tasks. A young office worker with good eyesight reviewing laser printed documents has different visual needs than an older worker with glasses at a computer terminal beside a window. The preferred thermal environment varies among workers over a range of humidity, temperature and airflow. But some of the largest and often uncontrolled changes have as their origin the external world – temperature, sunlight, wind, and moisture. A façade system must respond dynamically over a very wide range of these conditions in a manner that meets numerous occupant and owner needs. The building envelope and its support systems must control interior daylight and sunlight and associated temperatures over a relatively narrow indoor range while the exterior variation is enormous, spanning from darkness to direct sun; and controlling temperatures that range from –40C to +50C. There is no static façade solution that can be optimized to provide good results at all times. One classic architectural response has been a well-insulated façade with minimal fenestration in which the glazing properties are a small contributor to total impacts. But this is no longer the case with the new generation of highly glazed building facades.

The only workable solution in such a situation is the use of “dynamic” façade systems whose properties can be actively controlled to achieve the desired operating properties in response to changing indoor and outdoor conditions. Furthermore since the façade systems will be more complex than existing static products, and since many new buildings also have more stringent requirements for security the facades introduce a new level of required integration with the rest of the building. In the best of the new solutions the facades play multiple roles throughout much of the occupied building in providing natural ventilation, daylight and thermal tempering. But this requires a degree of integration, beginning early in the design process, that is the exception, not the norm today. It also suggests levels of technology integration that are not routinely practiced in buildings, although they are consistently achieved in other manufacturing endeavours such as the automotive and aircraft industries. Finally it suggests the need for integration across the stages of the building life cycle, so that design intent is properly implemented during commissioning, and so building operators can effectively manage the commissioned systems over time as building use profiles change. To add to the difficulty these solutions will likely cost more than traditional solutions, at least for first cost, and in the risk averse, cost-conscious building industry this always presents a challenge.

“Advanced facades” today are characterized by three key features: systems integration, dynamic operation, and changing life-cycle performance issues. To better understand how facades can meet these challenges our work has raised a number of issues that are now being addressed by researchers and industry throughout the world. These are outlined below, with a brief description of our current work in each of these areas.

3. Challenges and Opportunities for Dynamic Façade Systems

a. Advanced facades require greater first cost investment in hardware and façade technology, some of which may be offset elsewhere in the building

In the majority of cases the additional technology needed to provide new levels of dynamic control will add to the first cost compared to a base case building. In some cases portions of this increased first cost will be offset by other design changes, e.g. smart glazings could allow smaller chillers or elimination of conventional blinds or shades. Modelling studies suggest these values could lie in the range of \$3-\$15/m^2 but field data are sparse. These offsets involve more than engineering calculations. Rightsizing a chiller system or eliminating it entirely requires risk assessment on the part of the engineer that the operation of the building by the owner for years to come will follow original design intent. The U.S. General Services Administration is now building an office building in San Francisco without mechanical cooling on many of its floors, using cross ventilation at night from automated, operable windows. This was only possible with substantial additional design and analysis, and from a motivated and knowledgeable client. **[1]** There are also operating cost savings, e.g. energy savings, as well that will partially or fully amortize the added first cost over longer time periods. Future credits for demand response and time-variable pricing of electricity as well as carbon emissions could all add to the owners’ annual benefits from buildings with advanced facades.

b. Advanced facades will require enhanced automation and better sensors and controls for optimal operations

In a small building with a few occupants the opening of a window or lowering of a shade might be done by the occupant based on a sense of the needs of the space. In a larger building with many occupants and a design strategy that might involve predictive algorithms, thermal storage and/or integration of façade and lighting systems, ad hoc control by occupants must be replaced by more reliable automated controls. Such controls will accept inputs from a wide range of building sensors (wired and wireless) as well as anticipatory signals for predicted evening wind and temperature, day ahead utility price signals and next day expected building occupancy. New low cost sensors with communications based on internet protocols have been developed and tested at our lab for motorized blinds and electrochromic windows. **[2]** Motors, actuators or dynamic coatings must activate reliably in response to control system outputs. **[3,9]** Building automation systems will provide enhanced software that tracks key system performance metrics over time, comparison to archived past performance data, fault detection and automated diagnostics to correct faults when they are discovered. Some of these services may be delivered remotely over the internet. Since the skills to operate such systems are not cheap a new paradigm of providing expert operators with control over many buildings at a central location makes sense if the two-way communications and controls provides the data and feedback necessary**.** Our work also extends to involving building occupants directly into providing feedback via the web to building operators.

c. Design of advanced facades will require better simulation and design tools, better ways of organizing the design team around the goals and better tools for commissioning and building operations

Traditional design of simple façade systems is based on minimal use of simulation tools primarily for peak load estimates. Dynamic systems that are responsive and properly sized for all expected operating conditions must be studied under these diverse conditions. The ability to create and model a "virtual building" and explore its operational modes with different glass façade controls is a major objective of new long term research work. Increasingly the facades are being linked to building ventilation systems, both natural and mechanical, to provide some or all of the fresh air and thermal comfort. This requires a new degree of tool integration so that thermal interactions of facades are properly considered in whole building energy modelling. **[9]**

Better tools for modelling all aspects of complex, dynamic facades are now being developed and should be available over the next few years. In the U.S. the WINDOW/THERM/Optics suite of tools is being extended to model more optically complex glazings. **[4]** Radiance already does a good job of modelling light in complex spaces but new improvements are underway as part of IEA task 31 so that Radiance can better model more complex glazing materials. **[5]** The primary building energy simulation tool in the US is DOE-2, developed over 20 years ago. This is now being replaced by a new and more powerful whole building simulation tool, EnergyPlus, with numerous new features such as thermal comfort, moisture adsorption, etc. A companion tool, SPARK, also allows complex HVAC systems and control algorithms to be modeled. **[6]** EnergyPlus is now linked to COMIS for multizone air movement and links to CFD tools are also being explored. The long-term goal is a suite of tools that shares the same building data model and facilitates exploration of virtually any design, from schematics to design development, and even through commissioning and operations of the systems. The underlying building data model from the International Alliance for Interoperability is well developed but must be extended further to meet specific façade modelling needs**. [7]**

d. Technological Innovation will improve performance and reduce costs

Although glass and operable shading systems have been part of buildings for many years continued innovation drives progress towards meeting new performance goals more effectively and more economically. Innovations over the last 20 years have reduced the overall U value of best-available glazing from about 3 W/m^2-C to about $1W/m^2$-C with future potential to fall to .6. Highly spectrally-selective glazings transmit nearly all visible but reflect most of the near-infrared radiation in sunlight that contributes to excessive cooling loads. Motorized shades, blinds and louvers use improved motors, controllers, sensors, and wired and wireless networks. There is a renewed push toward smart glazings, with coatings that dynamically change from clear to absorbing or reflective to reduce solar gain and control glare, a crucial function in an office environment. Delivering dynamic, responsive control of solar gain and glare, but permitting daylight use, is still the holy grail of façade technology. The emerging generation of electrochromic glazings has the best chance of providing these capabilities in the years ahead. R&D is focused now not only on development of better, cheaper coatings with improved durability and greater dynamic range but also on the systems integration issues that will allow maximum energy and non-energy benefits to be achieved**. [8. 9]** A new three-room field test facility has just been opened at LBNL to evaluate these systems solutions and directly measure engineering performance data as well as occupant response to the systems. The research is aimed at creating heightened interest in "plug and play" technologies so that smart glass, dimmable lighting and other systems elements work seamlessly as a system without conflicts.

e. Field testing of design concepts and technologies plays a crucial role in understanding and validating system performance

In an ideal world with perfect modelling tools one could move with confidence from tool predictions to construction of the building and then occupancy. In the real world it is useful to explore issues, options and solutions in a testbed or mock-up whenever feasible prior to completing construction documents or pouring concrete for a real building. Mock-ups and test rooms can be expensive but provide levels of performance detail that are currently unattainable any other way. For system integration studies they are essential tools for studying and understanding complex systems where the performance of some parts depends on the performance of all other parts and systems. Testbed studies can accommodate human factors experiments in the spaces as well as engineering optimization studies, and they provide invaluable data that should be immediately useful to other owners, designers and manufacturers of façade systems. Over the past 5 years LBNL has examined automated blinds and electrochromics in test rooms in buildings in California with an emphasis on the integration of solar control, glare control and daylight dimming. **[8,9]** New studies will continue this work at the LBNL test facility, and near New York City in an outdoor mock-up of a major new office building with an all glass façade, exterior fixed shading and interior automated blinds and dimmable lighting.

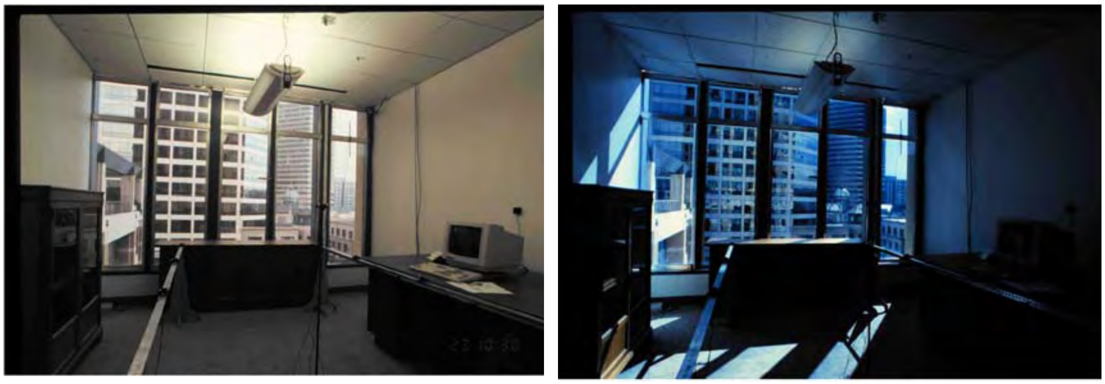

Figure 2. Interior view of test room on partly cloudy day at Oakland Federal Building. The electrochromic windows are in the clear state under diffuse light conditions (left). When sun enters the window, they switch to their fully colored state (right)

f. The performance of buildings and their infrastructure systems will be more intimately linked to the electric grid.

Several years ago California experienced electricity shortages and more recently the northeast part of the country experience a massive power outage. California is beginning to provide economic incentives for customers to adopt smarter building control strategies that are responsive to real time price signals from the electric grid. With proposed critical peak pricing programs in California, for 15 to 30 hours per year, with day-ahead notice, electric prices will rise ten-fold, with offsetting reductions during non- peak periods. Buildings with smart, responsive controls that can minimize electric use but maximize productivity and comfort can benefit from these new rates. [9] The challenge for facades is to make the critical engineering tradeoffs between cooling and lighting use, while accommodating thermal comfort, glare and satisfaction of users. Responsive systems that are put in place for such price-responsive rates structures would also function well during emergencies caused by natural or man-made disasters or disruptions.

g. Human factors issues will influence design solutions

In the process of optimizing building design there is sometimes a tendency to forget that (most) buildings exist to house the activities of people and must therefore accommodate their needs as well as their wants and perhaps even their whims. These vary somewhat because human physiology varies but there are also preferences and desires that may be harder to understand and design for. Extreme conditions, e.g. high levels of glare or high mean radiant temperatures, can clearly have a quantifiable impact on some people. Some aspects of occupant satisfaction and preferences can be effectively assessed but others remain elusive. The single largest annual economic impact in buildings is the salary of occupants. Ultimately the impact of the façade on overall productivity is probably quantifiable under some conditions but not within the useful limits at the current time.

ACKNOWLEDGEMENTS

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Advanced Interactive Facades – Critical Elements for Future Green Buildings?

Stephen Selkowitz Department Head[1]
Øyvind Aschehoug, Professor[2]
Eleanor S. Lee, Scientist[3]

[1] Department Head, Building Technologies Department, Lawrence Berkeley National Laboratory. Phone: +1 510 486-5064. Fax: +1 510 486-4089. E-mail: SESelkowitz@lbl.gov
[2] Visiting Professor, Norwegian University of Science and Technology, Trondheim. Phone: +1 47 73 59 50 46. Fax: +1 47 73 59 50 45. E-mail: Oyvind.Aschehoug@ark.ntnu.no
[3] Researcher, Building Technologies Department, Lawrence Berkeley National Laboratory. Phone: +1 510 486-4997. Fax: +1 510 486-4089. E-mail: ESLee@lbl.gov

1. INTRODUCTION

Building designers and owners have always been fascinated with the extensive use of glass in building envelopes. Today the highly glazed façade has almost become an iconic element for a "green building" that provides daylighting and a visual connection with the natural environment. Even before the current interest in green buildings there was no shortage of highly glazed building designs. But many of these buildings either rejected sunlight, and some associated daylight and view with highly reflective glazings or used highly transmissive glass and encountered serious internal comfort problems that could only be overcome with large HVAC systems, resulting in significant energy, cost and environmental penalties.

From the 1960's to the 1990's innovation in glazing made heat absorbing glass, reflective glass and double glazing commonplace, with an associated set of aesthetic features. In the last decade there has been a subtle shift from trying to optimize an ideal, static design solution using these glazings to making the façade responsive, interactive and even intelligent. More sophisticated design approaches and technologies have emerged using new high-performance glazing, improved shading and solar control systems, greater use of automated controls, and integration with other building systems. One relatively new architectural development is the double glass facade that offers a cavity that can provide improved acoustics, better solar control and enhanced ventilation.

Taken to its ultimate development, an interactive façade should respond intelligently and reliably to the changing outdoor conditions and internal performance needs. It should exploit available natural energies for lighting, heating and ventilation, should be able to provide large energy savings compared to conventional technologies, and at the same time maintain optimal indoor visual and thermal comfort conditions. As photovoltaic costs decrease in the future, these onsite power systems will be integrated within the glass skin and these facades will become local, non-polluting energy suppliers to the building. The potential for facilitating sustainable building operations in the future by exploiting these concepts is therefore great.

While the potentials are large, most are as yet undocumented and unrealized. The main R&D efforts in this sector are happening in Europe, where a number of recent high-profile buildings have demonstrated some of the technologies available today, notably in Germany, Netherlands, and UK. There has been less activity to date in North America although some noteworthy buildings have been constructed in the last few years.

Over the last 10 years LBNL has undertaken a research effort to explore the operation of interactive technologies for facades, focusing on daylight utilization, sun and glare control, and electric lighting controls with a prime motivation to reduce energy and electric demand. A focus on engineering and energy efficiency performance issues has been balanced with an occupant and owner perspective as well. The work explored the performance of special daylighting glazings, motorized blinds and electrochromic glazings. In 2001 in a broader effort to better understand how to facilitate development and adoption of these strategies and technologies, LBNL completed an initial assessment of high-performance commercial building facades in Europe and the US, documenting the current technology, tools and design practice (Lee et al. 2002). A key conclusion was that there is little hard performance data available to substantiate the commonly articulated claims about the merits of such facades. Beginning with a overview of the state of the art, the report outlines the critical R&D needs that must be addressed before such technologies can be routinely engineered to reliably deliver desired performance. These include sophisticated performance prediction tools, control algorithms for the complex interaction of different systems, design guidelines, post-occupancy studies of built cases etc. Other issues requiring further exploration are the comfort and productivity effects of these systems and the impacts of embodied energy use on life-cycle assessment of façade performance (Andresen et al. 2001).

Owners and designers indicated that the ability to reliably predict performance is a key prerequisite to further progress with advanced facades, as is the availability of cost effective hardware systems. Performance in this context includes the direct use of energy and associated electric demand and environmental impacts. But it should also include non-energy benefits associated with occupant comfort and satisfaction, and ideally productivity, as well as measures of indirect environmental impact such as embodied energy associated with the façade systems. Providing these answers will be a long and difficult challenge and LBNL has begun to address these needs by engaging an industry consortium in the US and collaborating with research partners overseas.

Interest in green buildings and sustainable design has often focused on the emissions and environmental impacts associated with life cycle assessment of materials used in the buildings. But the few studies available in this field suggest that the largest overall environmental impacts are those resulting from annual energy use associated with providing thermal and visual comfort in a building. The underlying energy and comfort performance issues are very well understood. A glass-enveloped building will normally be cold in the winter and warm in the summer, quite the opposite of our comfort preferences. The physical performance also leads directly to comfort impacts:

Winter heat loss => energy for heating
- ⇨ thermal comfort problems:
  - ⇨ low temperature radiation draught
  - ⇨ cold surface convention flow
  - ⇨ condensation, mold

Summer solar gain => electricity for ventilation and cooling
- ⇨ thermal comfort problems:
  - ⇨ direct radiation gain in occupied zones
  - ⇨ air temperature above comfort level

Daylighting => glare from high luminance sky, reflected daylight
- ⇨ glare from direct sunshine in occupied zones
- ⇨ veiling reflections in computer screens

For a single building the energy impact is seen by the building owner ($10-20/sq.m.-yr) as one of many operational costs, whose magnitude is small compared to direct costs of ownership, e.g. maintenance, taxes, lease cost. But cumulative costs for the nation are large, as is the overall regional and global environmental impact of energy use. Glazing in commercial buildings today is directly responsible for about 1.3 Quads of annual energy use and indirectly influences another 1 Quad due to daylighting potentials. These energy impacts alone have an overall direct annual cost to building owners exceeding $15B/year with large associated greenhouse gas emissions. In the long-range view these impacts are unnecessary and unsustainable. The challenge is to reduce the thermal loads to the point where the winter solar gains and annual daylight benefits exceed the losses, thus erasing the current impacts and making the facades "energy neutral". An ultimate objective is to properly account for the embodied energy in these calculations and to ultimately utilize energy generation in the skin to make these facades act as "net energy suppliers" to buildings, with appropriately low overall environmental loadings.

In this paper we review the recently completed work referenced above to better understand the nature of the challenges to achieving this goal, and discuss the nature of the collaborative effort and the work now underway to address the challenges, and the results to be expected as the work progresses.

2. THE INTERACTIVE FAÇADE

How can we convert a $15B/year energy problem into a sustainable design solution? The interactive façade will have to include systems that correct or moderate the performance of the glass as the outdoor conditions change, also allowing for individual occupant adjustment of the indoor comfort parameters. A static all-glass envelope will not be able to give optimal performance except for a few time periods during the year. Adding blinds that are irregularly controlled by occupants will not fundamentally change the performance picture. The conclusion is therefore that we need an intelligently controlled, dynamic envelope.

The current philosophy is to design the envelope with responsive, interactive systems, also often called “intelligent envelopes” (Wigginton et al. 2002). The envelope systems should react sensibly to the changes in the exterior climate and adjust solar gain, daylighting, heat loss, ventilation, and venting to the changing needs of the occupants and the building. In general, smart building controls and good occupant-level controls should be consistent and compatible but there are differences in philosophy and implementation. There is increasing evidence that occupants prefer strongly to have some level of personal control of their local indoor environment and that this might result in better overall work satisfaction and perhaps better performance and productivity. But there are potential conflicts as well - the occupant who prefers to have the blinds open on the west orientation to watch the afternoon sun may create problems for a building manager trying to minimize peak building cooling loads. Dynamic control is essential in all cases- the hierarchy of control priority is a matter for further exploration. Energy and comfort criteria are likely to be well correlated. Occupant preferences for temperature, light levels, view, etc are known to be consistent for a single individual but more variable between different individuals, thus providing some potential integration challenges.

The interactive façade concept is thus an effective starting point both to actively manage the changing “incident” climatic conditions and occupant interior needs based on both changing tasks and variable preferences. But the investment in new façade concepts also offers more direct exploitation of the natural energy flows offered by the external climate. This starts with better utilization of energy flows associated with daylighting and useful solar gain, but could be expanded by including wind and buoyancy driven natural ventilation, and building integrated photovoltaic systems, BIPV. The traditional role of the envelope as a filter is being replaced or supplemented with a more active role as an energy collector and transport system. Of course these new functions potentially add complexity and cost to the envelope, both in hardware and in “process” (both design and operations). These systems will ultimately only be widely used if their overall lifecycle benefits, measurable and perceived, exceed their costs and potential liabilities. That challenge defines the work ahead.

3. STATE-OF-THE-ART IN EUROPE AND U.S.

The all-glass building has for some time been a dominating part of new architecturally high-profile buildings in Europe, often designed by internationally-known architects. One important premise is that office workers have the legal right to daylight and view out at their workstations through building codes and health legislation in most European countries, contrary to the US situation. This often leads to extended floor plans with shallow perimeter zone depths, differing from practice in the U.S. which is characterized by more compact floor plates with less perimeter. Floor plans with extended perimeters often cost more than a compact design and may have greater thermal skin loads if the envelope is not suitably designed. The extended floor plan in Europe also permits greater use of natural ventilation via operable windows. In many European countries the ability to open a window is also considered a fundamental occupant amenity.

Recent research has shown that many occupants value the access to daylight and view, and the ability to locally control their environments. There is some evidence, largely anecdotal, that workers in spaces with daylight, view and control over their workplaces may demonstrate increased productivity. Even a very slight increase in overall productivity can provide large economic benefits and quickly pay for almost any indoor environment improvement, provided of course that this connection can be proven. This argument is now exploited by many architects in convincing their clients of the feasibility of all-glass buildings, despite the fact that there is little hard evidence to support it. But in Europe legal requirements and workplace expectations also reinforce these decisions, unlike in the U.S. Our informal surveys in the U.S. in 2001 indicated that owners were aware of, and interested in, the arguments in support of potential non-energy benefits of glazing and daylighting but in the absence of well documented data with a plausible causal link were skeptical and unwilling to make additional investments on this basis alone.

In the last decade European design of all-glass buildings has led to an interest in, and development of a double façade construction in order to be able to cope with the environmental problems associated with the highly-glazed facades. The construction encompasses two glass skins separated by a cavity ranging from approximately 15 – 150 cm. The double façade cavity serves several important functions. It provides a protected location for shading systems, and excess solar gain can be extracted from the cavity before it reaches the fully tempered areas and result in over-heating. In many buildings, the cavity is also integrated in a natural ventilation scheme, which may allow reduced investments in the ventilation system that can help pay for the more costly façade. Double facades may also enable window opening in high-rise buildings and reduce acoustic impacts of open windows with respect to street noise in urban areas. The systems have been used in small scale, low rise buildings as well as very large high rise construction. The glazing configurations and venting/ventilation schemes vary widely. From a design, construction, cost and commissioning perspective these façade systems present many new challenges.

The major European cities have already a large sample of such glass buildings in their commercial centers, most prominently in the UK, Germany, Switzerland and Netherlands, but also in other western European countries. The clients are often high-tech industries or financial institution, and the buildings are almost always presented officially as energy-conscious and “green”. Some research has been conducted through the R&D programs of the European Community, but the reality is that we do not really know in detail how they perform. Increased thermal and acoustical insulation, and opportunities for venting and natural ventilation are often listed as advantages for double facades. Increased fire risk and sound transmission via windows are noted as potential problem areas. The systems are costly as most are designed as one-of-a-kind systems although there is now a growing interest in standardizing some of the elements or systems. Judging from the pace of construction alone there is no lessening of the interest in these design solutions in Europe. In the U.S. we are now seeing the first “generation” of new double façade buildings reaching completion and occupancy, with more new ones underway. As in Europe it will be increasingly important to understand and document the performance these systems so that new designs are continuously improved.

Although double façade systems have captured the attention of many, our interest are more broadly on the topic of advanced interactive facades, which includes, but is not limited to, this subset of solutions. In section 4 our comments are addressed to a wide range of adaptive, intelligent envelope solutions.

4. PERFORMANCE ISSUES, TRENDS AND R&D DIRECTIONS

As with many trends and changes in architectural practice, the profession evolves slowly in planned and unplanned pathways, driven by a variety of business, technological, environmental, sociological and architectural factors. It is often difficult to understand the interplay of forces that shape progress with the advantage of hindsight- it is even more difficult to attempt to do this in "real time". However in reviewing trends in sustainable design and advanced facades in Europe and the US some early conclusions can be drawn and some issues appear to stand out as more significant than others. We summarize these issues, trends and R&D needs below in 6 categories and illustrate the points with experience from several recent projects. We mix together some trends that characterize market directions today with other future performance needs and objectives for R&D on advanced facades in the coming years.

4.1 Design of advanced facades will require better simulation and design tools, better ways of organizing the design team around the goals and better tools for commissioning and building operations

Traditional façade design is based on minimal use of simulation tools, primarily for peak load estimates. Dynamic, responsive systems must be analyzed under a range of diverse conditions for proper system sizing. The ability to create and model a "virtual building" and explore its operational modes with different glass façade controls is a major objective of new building energy simulation tool development such as EnergyPlus (http://gundog.lbl.gov). Tools that provide accurate optical and thermal properties of the façade elements, e.g. glazings, are available (http://windows.lbl.gov/software/default.htm) although more work is underway on the subject of optically complex glazings and shading systems. Advanced facades are now asked to provide additional control of ventilation air and daylight, requiring expanded use of tools that address CFD and daylighting performance for both energy studies and comfort assessment. Accurate modeling of performance is needed so that mechanical systems can be properly sized to meet loads. This requires a new degree of tool integration so that thermal and daylighting interactions of facades are properly considered as part of whole building energy modeling. In the future the modeling investment made for design might also be re-used for commissioning and operations (Lee et al. 2002).

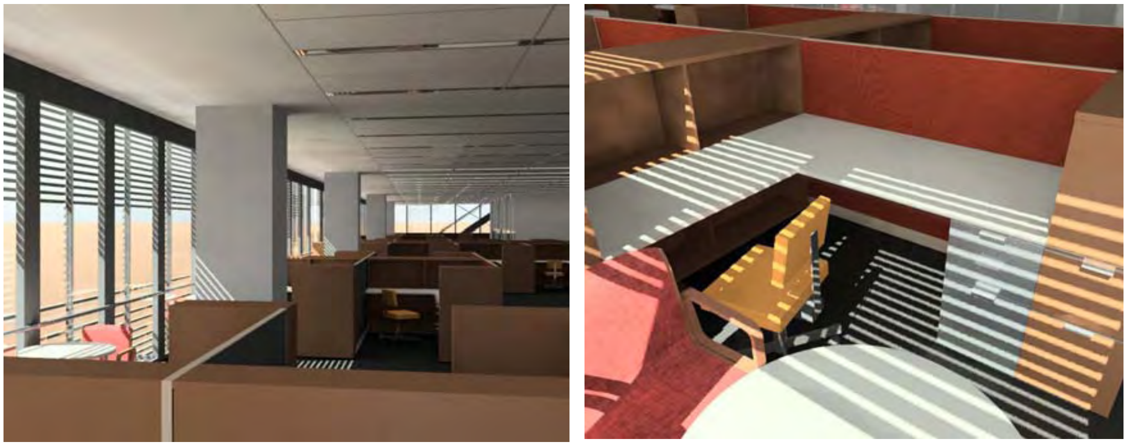

Figure 1 Work in progress to develop automated interior shading control, glare control, and daylight dimming lighting controls for an all glass façade in New York City. The Radiance simulation program (radsite.lbl.gov) is used to simulate the dynamic performance of interior operable shading with fixed exterior sun control elements, for different orientations; results will be used to develop shade control strategies.

4.2 Advanced facades require greater first cost investment in hardware and façade technology, some of which may be offset by savings elsewhere in the building

In most cases the additional technology needed to provide new levels of dynamic control will add to the first cost compared to a base case building. In some cases portions of this increased first cost will be offset by other design changes, e.g. smart glazings could allow smaller chillers or elimination of conventional blinds or shades. Modeling studies suggest these values could lie in the range of \$30-\$150/m^2 but field data are sparse. These offsets involve more than detailed engineering calculations. Rightsizing a chiller system requires risk assessment on the part of the engineer that the operation of the building by the owner for years to come will follow original design intent. The U.S. General Services Administration is now building an office building in San Francisco without mechanical cooling on many of its floors, using cross ventilation at night from automated, operable windows. This was only possible with substantial additional design and analysis, and from a motivated and knowledgeable client who is able to link performance objectives in the design phase with commissioning and operational integrity after construction is complete (McConahey et al. 2002). There are also the traditional operating cost savings, e.g. energy savings, as well that will partially or fully amortize the added first cost over longer time periods. Future credits for demand response and time-variable pricing of electricity as well as carbon emissions could all add to the owners' annual benefits from buildings with advanced facades.

4.3 Advanced facades will require enhanced automation and better sensors and controls for optimal operations

Manual operation of windows or shades might work in home and some small buildings. In a larger building with many occupants and a design strategy that might involve predictive algorithms, thermal storage and/or integration of façade and lighting systems, ad hoc control by occupants must be replaced by more reliable automated controls. Such controls will accept inputs from a wide range of building sensors (wired and wireless) as well as anticipatory signals for predicted evening wind and temperature, day ahead utility price signals and next day expected building occupancy. New low cost sensors and controls with communications based on internet protocols have been developed and tested at our lab for motorized blinds and electrochromic windows (Rubinstein et al. 2000). Motors, actuators or dynamic coatings must activate reliably in response to control system outputs (Lee et al. 2003). Building automation systems will track and display key system performance metrics over time, providing comparison to archived performance data, and employ fault detection and automated diagnostics to correct faults when they are discovered. Our work also extends to exploring systems that provide building occupant feedback via the web to building operators.

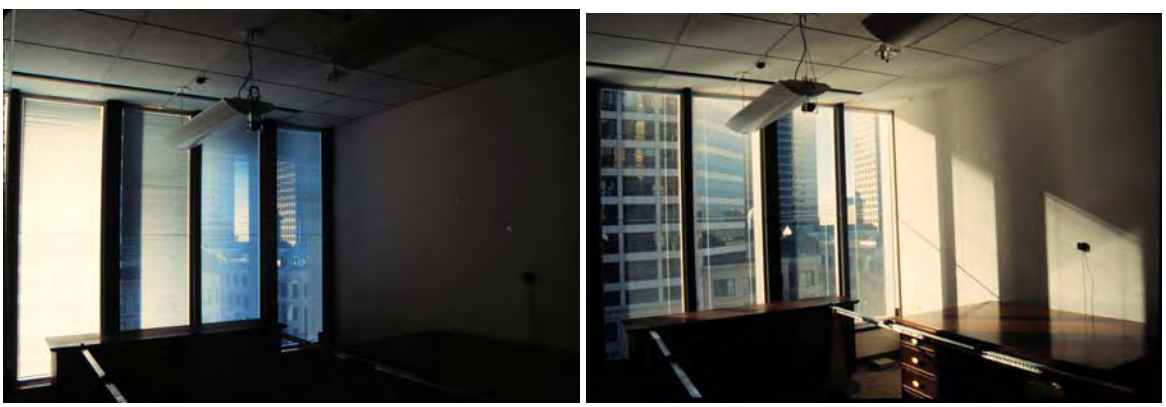

Figure 2 Smart controls on the automated blind systems (left photo) keep direct sun out of the space, reducing glare and cooling loads. The same hardware system with different control strategies (right photo) admits sunlight to offset heating loads but creates excessive glare.

4.4 Innovation will improve hardware performance and reduce costs

Innovations over the last 20 years have reduced the overall U value of best-available glazing from about 3 W/m^2-C to about 1W/m^2-C with future potential to fall to .6. Spectrally-selective glazings transmit nearly all visible but reflect most of the near-infrared radiation in sunlight, thus reducing cooling loads. Delivering dynamic, responsive control of solar gain and glare, but permitting daylight use, is still the holy grail of façade technology. Improved motorized systems will be joined by the emerging generation of electrochromic smart glazings with coatings that dynamically change from clear to absorbing or reflective to reduce solar gain and control glare. R&D is focused now not only on development of better, cheaper coatings with improved durability and greater dynamic range but also on the systems integration issues that will allow maximum energy and non-energy benefits to be achieved (Lee et al. 2002). A new three-room field test facility at LBNL is now evaluating first generation systems solutions, directly measuring engineering performance data as well as occupant response. A longer term objective is “plug and play” technologies so that smart glass, dimmable lighting and other systems elements work seamlessly as a system without conflicts.

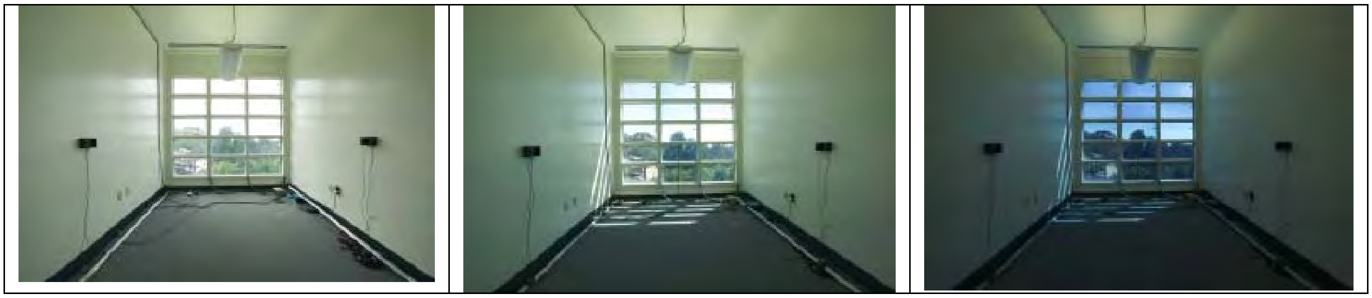

Figure 3 New LBNL facility for comparative field tests of advanced facades. Electrochromic glazings are controlled real-time to meet design illuminance but control solar gain and glare. Left: Under cloudy conditions the glass is at maximum transmittance. Center: When sun comes out the window begins to darken. Right: After 5 minutes the window is fully darkened but the lights are on to meet illuminance levels.

4.5 Field testing of design concepts and technologies plays a crucial role in understanding and validating system performance, and in building confidence in system performance.

Despite advances in modeling, measured field data will be required to convince many owners of the performance potentials. Field studies by LBNL over the last 8 years has provided limited data on automated blinds and electrochromics in test rooms in buildings in California with an emphasis on the integration of solar control, glare control and daylight dimming (Lee et al. 2000). New studies will continue this work at the LBNL test facility, and near New York City in an outdoor mock-up of a major new office building with an all glass façade, exterior fixed shading and interior automated blinds and dimmable lighting. These facilities not only provide engineering data and user response information but allow potential owners and design teams to experience the space firsthand, a critical step in adoption of new technology and design solutions.

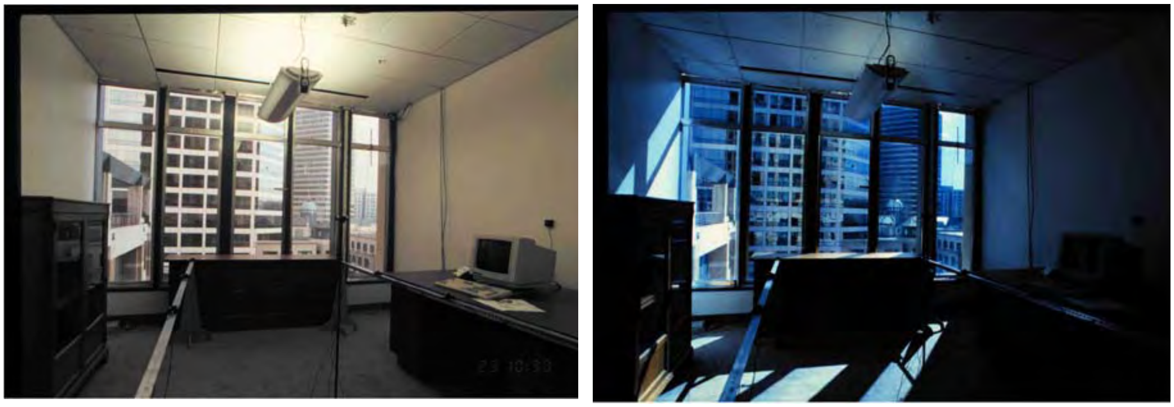

Figure 4	Initial testing of electrochromic glazings in GSA office building in Oakland CA.; left: glazing is clear under dark overcast conditions; right: glazing in lowest transmittance state with direct sun (Lee, et al. 2003).

4.6 The performance of buildings and their infrastructure systems will be more intimately linked to the local or regional electric grid.

Sustainable design suggests that more attention be paid to the overall environmental impact of the building. Emissions from electrical energy generation are one of the largest environmental impacts of building operations. Although buildings may appear as standalone objects they are interdependent parts of local, regional and national electric grids, and the gas transmission infrastructure. Recent California experience with electricity shortages and more recently the northeast US experience with a massive power outage reminds us of the consequences of lack of reliable energy supply. More aggressive load management strategies may offer quicker and more cost effective alternatives to building more power plants. California is beginning to provide economic incentives for customers to adopt smarter building control strategies that are responsive to real time price signals from the electric grid. With proposed critical peak pricing programs in California, for 15 to 30 hours per year, with day-ahead notice, electric prices will rise ten-fold for several hours during hot summer days, with offsetting reductions during non- peak periods. Buildings with smart, responsive controls that can minimize electric use but maximize productivity and comfort can benefit from these new rates (Lee et al. 2002). The challenge for facades is to make the critical engineering tradeoffs between cooling and lighting use, while accommodating thermal comfort, glare and satisfaction of users. In these cases building owners might be given capabilities to effectively override the choices of individuals under critical demand response conditions. Responsive systems that are put in place for such price-responsive rates structures would also function well during emergencies caused by natural or man-made disasters or disruptions.

5. CONCLUSIONS

There is growing interest in highly glazed building facades, driven by a variety of architectural, aesthetic, business and environmental rationales. The environmental rationale appears plausible only if conventional glazing systems are replaced by a new generation of high performance, interactive, intelligent façade systems, that meet the comfort and performance needs of occupants while satisfying owner economic needs and broader societal environmental concerns. The challenge is that new technology, better systems integration using more capable design tools, and smarter building operation are all necessary to meet these goals. The opportunity is to create a new class of buildings that are both environmentally responsible at a regional or global level while providing the amenities and working environments that owners and occupants seek.

ACKNOWLEDGEMENT

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Integrating Automated Shading and Smart Glazings with Daylight Controls

Stephen Selkowitz

Eleanor Lee

Lawrence Berkeley National Laboratory

Keywords: daylighting, controls, smart glazing, shading, field testing, IEA31

1. INTRODUCTION

Most commercial buildings utilize windows and other glazed envelope components for a variety of reasons. Glass is a key element in the architectural expression of the building and typically provides occupants with a visual connection with the outdoors and daylight to enhance the quality of the indoor environment. But the building skin must serve a crucial function in its role to help maintain proper interior working environments under extremes of external environmental conditions. Exterior temperature conditions vary slowly over a wide range and solar and daylight fluxes can vary very rapidly over a very wide range. The technical problem of controlling heat loss and gain is largely solved with highly insulating glazing technologies on the market today. The challenge of controlling solar gain and managing daylight, view and glare is at a much earlier stage. In most cases a static, fixed control solution will not suffice. Some degree of active, rapid response to changing outdoor conditions and to changing interior task requirements is needed. This can be provided with technology within the glass or glazing assembly itself, or the functionality can be added to the façade either on the interior or exterior of the glazing. In all cases “sensors”, “actuators”, and a “control logic” must be applied for proper functionality. Traditional manually operated mechanical shading systems such as blinds or shades can be motorized and then controlled by occupant action or by sensors and building controls. Emerging smart glass technology can dynamically change optical properties, and can be activated manually or by automated control systems. In all of these cases electric lighting should be controlled to meet occupant needs, while maximizing energy efficiency and minimizing electric demand. As with the fenestration controls, lighting control requires sensors (photocells or the human eye), actuation (switching or dimming) and a control logic that determines what action should be taken under each set of conditions. Some variation on the combination of all of these elements comprises the typical equipment and systems found in most commercial buildings today. The new challenge is to provide a fully functional and integrated façade and lighting system that operates appropriately for all environmental conditions and meets a range of occupant subjective desires and objective performance requirements. And finally these rigorous performance goals must be achieved with solutions that are cost effective and operate over long periods with minimal maintenance.

This paper explores two classes of emerging solutions for the challenge outlined above. In each case the challenge is how to provide a wide range of performance and comfort with a highly glazed façade. In one case we explore several options based on motorized blinds and roller shade systems and in the other we explore the use of electrochromic glazings. Each study involves both engineering measurements and some exploration of human factors issues. Initial results are presented and the field studies continue with both systems to better understand performance options.

2. Dynamic, Integrated Façade Systems

2.1 Overview of Automated Building Systems

Manual operation of windows or shades might work in home and some small buildings. But in a larger building with many occupants and a operating design strategy that might involve predictive algorithms, thermal storage and/or integration of façade and lighting systems, ad hoc control by occupants must be replaced by more reliable automated controls. Such controls will accept inputs from a wide range of building sensors (wired and wireless) as well as anticipatory signals for predicted evening wind and temperature, day ahead utility price signals and next day expected building occupancy. New low cost sensors and controls with communications based on internet protocols have been developed and tested at our lab for motorized blinds and electrochromic windows. Motors, actuators or dynamic coatings must activate reliably in response to control system outputs. Building automation systems will track and display key system performance metrics over time, providing comparison to archived performance data, and employ fault detection and automated diagnostics to correct faults when they are discovered. Finally the best systems would provide building occupant feedback via the web to building operators. In advancing toward this vision we have focused a series of studies over the last decade on the challenge of developing responsive facades that are fully integrated with automated dimmable lighting systems.

2.2 Motorized Blind Systems

Venetian blind systems are well-established technologies for controlling solar gain and glare. Because both the optical properties of the slats and their tilt can be controlled there is a wide range of optical control available. However manually operated blinds are rarely controlled in an optimal manner and when rooms are empty but the heating and cooling systems are operating they may not be operated at all. Motorizing the blinds and adding appropriate sensors and controls is thus an approach that should permit better control of both energy use and comfort, assuming that the proper control strategies can be successfully developed, implemented and maintained. These systems are not commonly available in the U.S., nor are systems that further link to automated lighting controls. Beginning with “off the shelf” components we developed and tested these systems in two identical side by side test rooms in a southeast facing office building in Oakland, CA. (Figure 1) Not only were cooling and lighting energy savings achieved, and peak electrical benefits measured but the resultant automated systems were acceptable to occupants, in a limited occupancy study. Despite the success of the demonstration, the lack of a cost effective system delivered by a single vendor or groups of vendors continues to limit use of such systems.

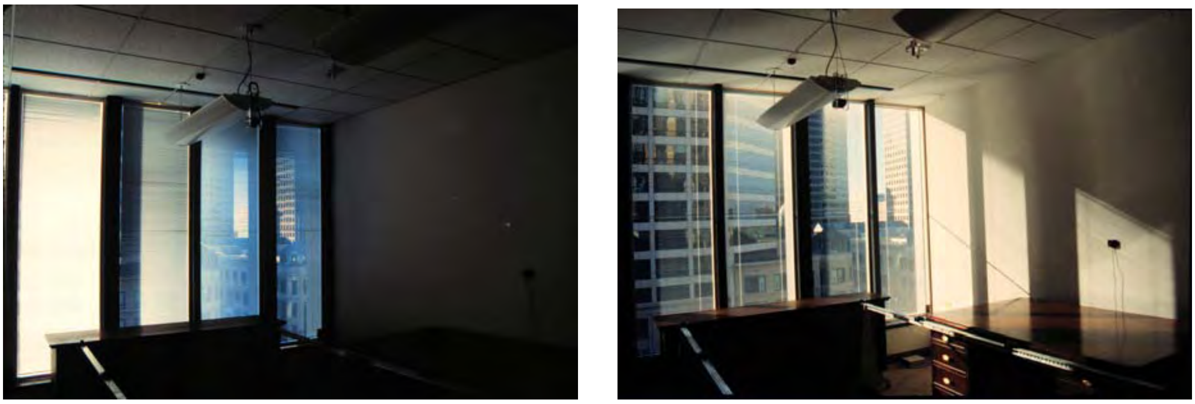


Figure 1: Smart controls on the automated blind systems (left photo) keep direct sun out of the space, reducing glare and cooling loads. The same hardware system with different control strategies (right photo) admits sunlight to offset heating loads but creates excessive glare.

2.3 Motorized Shade Systems

Roller shade systems are available with fabrics encompassing a wide range of solar optical properties. Although mechanically simpler, the shade systems have more limited optical control than blinds in terms of position, although it is also possible to layer blinds or use variable fabrics. A new field test program is now underway using an automated shade system in conjunction with a high transmittance, all glass façade for the New York Times headquarters building under design for a site in New York City. The 52-story building will utilize fixed exterior shading and fritted glass in some locations but will require shades for sun control and glare control and for thermal and visual comfort as well as energy management. In these tests a 450 square meter testbed was constructed near the site and the southwest corner of the building was reproduced at full scale and fully furnished. Two different shade manufacturers are testing products and two different dimmable lighting systems are also installed, together with different sensors and control strategies. (Figure 2) In addition to energy use, computer screen visibility is being studied to determine the best shade properties and operating strategy. (Figure 2) Testing will be undertaken through mid-2004 to capture the full range of sun conditions.

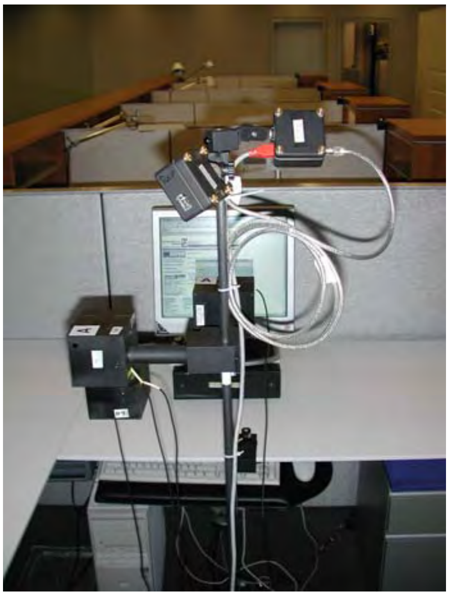
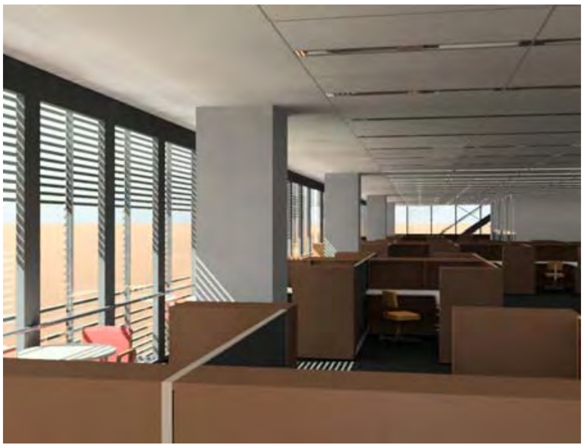


Figure 2: Interior photos of newly constructed testbed for New York Times building. At left, view toward the west façade, with two different shade systems partially deployed. At right, an instrumentation cluster at a workstation, including illuminance and luminance mapping sensors, and a webcam.

A series of RADIANCE simulations of the space were prepared to explore design and operating issues related to the shade systems and lighting controls. (Figure 3) Detailed optical properties of all interior furnishings were measured. RADIANCE images will allow extension of measured results to other orientations and to account for other site conditions such as adjacent buildings.



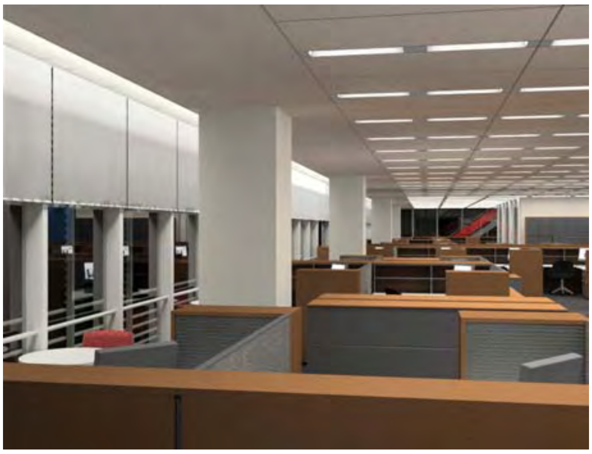


Figure 3: Initial RADIANCE simulations of the west façade of the New York Times building. Left: Without interior automated shading, the exterior ceramic rod shading system is insufficient to control glare on work surfaces. Right: A night view of a more refined image with actual furniture layout, electric lights on, with shades partially deployed.

2.3 Electrochromic "Smart Windows"

Researchers have been developing switchable "smart glazings" for over a decade and the laboratory accomplishments are now beginning to become available for field-testing in larger prototype form. These glazings require low voltage wiring linked to control systems. The actual performance in buildings will be a combination of the intrinsic properties of the materials as well as the operating strategy in the building. These operating strategies must be developed not only for energy and load control but to meet occupant needs in terms of the interior work environment. Field studies in test rooms and mockups are an important adjunct to the extensive computer modeling studies that have already been completed to quantify potential savings.

Following the successful test of the venetian blind systems in the Oakland test building described above in section 2.1, the window systems in the two test rooms were retrofitted with a first generation electrochromic switchable window. The optical system changed from a clear state with a transmittance of 51% to a dark state with a transmission of 11%. The dimmable lighting controls were modified to integrate with the electrochromic switching controls and a variety of control strategies were explored- e.g. minimize lighting, minimize cooling, control glare on computer screen. The system performed well although full switching could take in excess of 15 minutes and the coatings had a noticeable blue tint in the switched mode. When glazings were tested in the “minimize glare” mode the room could become so dark that electric lights were partially on, as shown below. Additional tests were undertaken with the upper row of small windows in a clearer state to admit daylight while the lower windows were darkened for glare control. These results suggest that overall architectural design of the façade is an important element in addition to the control strategies and the properties of the glazing itself.

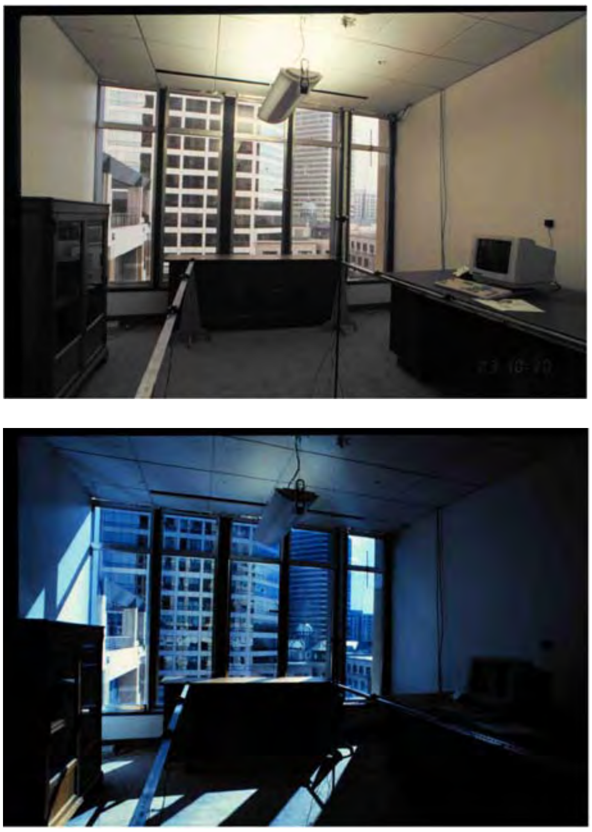


Figure 4: Electrochromic test rooms in Oakland, CA. The room at left is in a clear transmission state on an overcast morning; at right the sun has emerged and the window switches to its darkest state to control glare at the computer workstation.

Field tests in the Oakland building were limited to the orientation of the building and required that the electrochromic glazings be inserted inboard of the existing building glazing which could not be removed.

In 2002 we constructed a new test facility at LBNL with three side-by-side test rooms with unobstructed south views. The entire façade can be replaced. The lighting power and the heating and cooling in each room is individually monitored and the rooms have a full array of illuminance and luminance sensors for monitoring. The rooms have now been fitted with new electrochromic samples over the complete façade as shown in Figure 5. Since the prototypes were of limited size the façade requires 15 glazing panels.

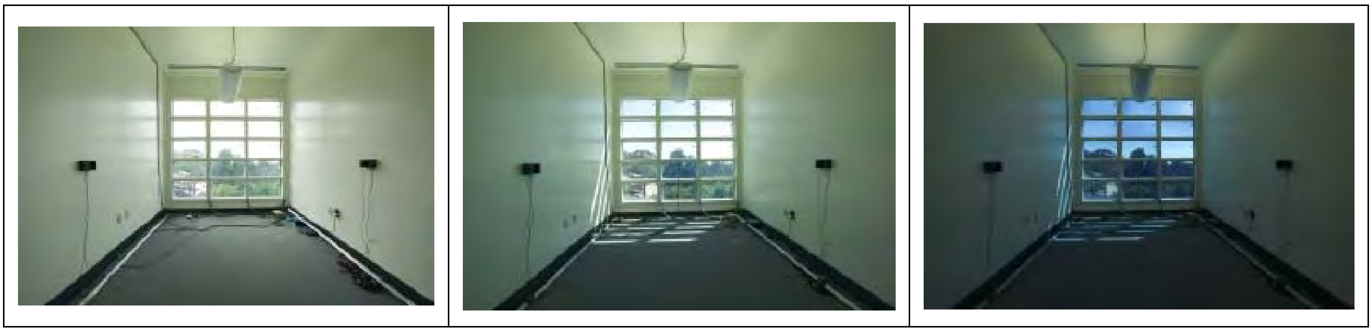


Figure 5: Three sequential views of one test room in the LBNL façade test facility, showing the darkening sequence. The visible transmittance of these prototypes can be switched from 60% to 4% in several minutes.

Engineering tests in the facility are now underway exploring the energy savings achieved with different control strategies. We have also conducted a series of human factors studies to determine desired operating and control parameters of the glazing and lighting systems and to better understand the human factors issues associated with smart control strategies. We plan to explore adaptive controls that will allow the "intelligent systems" to learn the preferences of users thereby improving the acceptability of these dynamic systems.

3.0 Summary

Growing interests in daylighting and sustainable design have led architects in the direction of using highly glazed building facades. In order for these designs to meet their performance objectives they will need to have a degree of consistent active management of solar and daylight transmittance through the building envelope that has rarely been achieved in buildings. Fortunately the technology elements to provide active control of fenestration transmittance and associated control of electric lighting in building interiors are now becoming more available**.** However it will take better and cheaper hardware, additional exploration of systems integration solutions, new sensors and controls, improved commissioning, a better understanding of occupant needs and preferences, and better real time, adaptive controls to fully realize the potentials of these emerging technologies. The continuing studies described here are intended to play a role in providing these solutions.

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We list references below to results of the studies cited above. Results of work in progress at the New York Times mockup and the Façade test facility at LBNL will be published in the next year.

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2.6 Acknowledgements

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technology, State and Community Programs, Office of Building Systems of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098, by the California Energy Commission, Public Interest Energy Research Program, and by the New York State Energy Research and Development Authority. We acknowledge the active support of numerous LBNL colleagues who are members of the project teams that carried out the projects described here.

Stephen Selkowitz, SESelkowitz@lbl.gov, Eleanor Lee, ESLee@lbl.gov

Lawrence Berkeley National Laboratory

Bldg 90-3111

1 Cyclotron Road

Berkeley, CA 94720

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FEATURE

SCE Refrigerated Display Case Efficiency Initiative

Dan Greenberg

What would you do if you found a hole in your refrigerator door that was responsible for 80 percent of the appliance's cooling load? You'd probably fix it or replace it in short order. Well, surprising as it may sound, there are huge numbers of such refrigerators operating throughout the world today, and nobody's doing a thing about them. Well, almost nobody, that is.

These refrigerators are the open vertical display cases found in most supermarkets and grocery stores, displaying everything from albacore tuna to zucchini. The gaping hole that gives consumers unfettered access to the goods makes these display cases notoriously inefficient at keeping products cold, but energy efficiency is of minimal importance to stores compared with the primary function of the cases—displaying and moving product.

Although display-case manufacturers have taken numerous steps in recent years to improve the energy efficiency of their products (offering higher-efficiency evaporator fan motors, high-efficiency lighting, and better insulation), no one has yet tackled the 900-pound gorilla that limits the efficiency of every open vertical display case—the simple fact that the cases are *open*. Studies have shown that simply placing doors on these cases would reduce their energy consumption by about 60 percent,[1] but that would be unacceptable to supermarket merchandisers, who fear that inserting any barrier between the consumer and the product would cause a decline in sales. The second-best option is to improve the function of the air curtain that creates a relatively ineffective thermal barrier between the refrigerated interior of the display case and the outside world. This is the quest of Ramin Faramarzi, manager of the Refrigeration and Thermal Test Center (RTTC) at Southern California Edison (SCE).

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For more information, contact Ted des Enfants, vice president and general manager, Fiberstars, New York, NY, 212-239-4498, ted@fiberstars.com, www.fiberstars.com.

RETROSPECTIVE

Whatever Happened to Smart Windows?

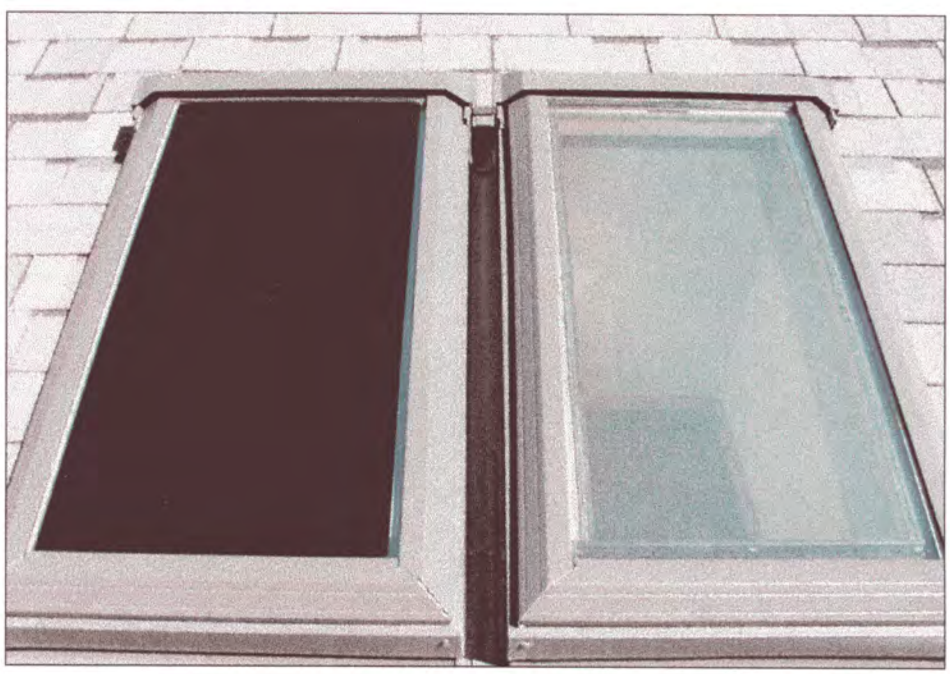
Kristi Kamm

The big news today in smart windows is that you can actually buy them for the first time. Two companies that we profiled in a previous article ("Electrochromics: Now You See It; Now You Don't," *E SOURCE Emerging Technology Currents*, no. 4, November 2000) have introduced high-end products for both commercial and residential buildings. A smart window looks like a conventional window but users are able to "tune" it by turning a dial or by using an automated lighting control system. Either action results in voltage variations that change the tint of the window from clear (or light blue) to dark blue, or anywhere in between, in response to the weather conditions or user preferences (**Figure 5**).[10]

In our previous article, we called smart windows a "revolutionary development in fenestration" because of their controllability. The windows can conserve energy used for heating and cooling by accepting more solar gain (heat from the sun) in the winter than in the summer (**Table 1**, page 11).[11] They can also minimize lighting energy consumption by allowing daylight in or can reduce glare by keeping daylight out. Eleanor Lee, a scientist at Lawrence Berkeley National Laboratory (LBNL), says that simulations of buildings with dimmable lighting systems shows that, compared with spectrally selective low-e windows, smart windows using electrochromic technology can reduce

Figure 5: A VELUX skylight in light and dark states

These 5.3-square-foot skylights use technology developed by SAGE Electrochromics to switch from light to dark or anywhere in between.



Courtesy: Sage Electrochromics Inc. [10]

total annual energy use in a building's perimeter zone by up to 30 percent.[12] And they can accomplish all of these feats while consuming very little energy.

Just the Two of Us

Two small companies, each formed solely to pursue smart window technology, have introduced products:

- *SAGE Electrochromics Inc.* At the end of 2002, after 12 years of development, SAGE's retailers introduced the company's technology for commercial and residential windows for the building supply market. SAGE applies a tint-controllable electrochromic coating to glass, which is then sold to window and skylight manufacturers to be made into finished products. SAGE's technology has passed independent durability testing conducted by the DOE.

- *Research Frontiers Inc.* For the past 40 years, researchers at Research Frontiers have been working on smart window technology. Retailers were finally able to introduce the company's technology to the residential and commercial window market in early 2004. Research Frontiers does not do any manufacturing itself; it licenses its suspended-particle technology to companies that produce a switchable window film that is different at the molecular level from SAGE's technology. Those companies send the film to window manufacturers, which laminate it to glass and finish the product.

Both SAGE and Research Frontiers are promising improved product performance within the next two years. For example, Research Frontiers is working to admit more light through the window when it's in the high-transmission state by raising the visible light transmission level from 25 to about 60 or 70 percent.[13]

Meanwhile, Thomas Richardson, staff scientist at LBNL, is aiming to up the ante with an altogether new technology. He is developing a window coating that adjusts from clear to reflective, instead of clear to tinted. This approach could result in much less solar heat gain while admitting the same amount of daylight, which could further reduce energy use in buildings.

If You've Got the Money, Honey

In the opinion of Roland Pitts, a scientist at the National Renewable Energy Laboratory, cost and market entry are the biggest issues for smart windows right now.[14] Product costs are very high because the products are basically hand-crafted, due to the small quantities that are currently being manufactured. An untinted skylight with a motorized open/close function and a rain sensor offered by VELUX costs \$400, but customers would have to spend \$1,800 (or \$340/ft^2) for one made with SAGE glass. Michael Myser, SAGE's marketing

Table 1: Attributes of smart windows

Smart windows can achieve a very dark tint and restrict the transmission of visible light, but they cannot become as clear as plain glass, which transmits 85 percent of visible light. Solar heat gain can be as low as 13 percent in the dark-tinted state for windows using SAGE Electrochromics' technology, but only 30 percent for windows using Research Frontiers' technology. Therefore, the SAGE product can more effectively minimize a building's cooling energy requirement. The warranty offered for products made with SAGE technology matches those offered for conventional windows—typically 10 or 20 years. Data has been provided by the technology developer except where noted.

	Research Frontiers	SAGE Electrochromics
Visible light transmittance	1 to 25 percent for a triple-paned window from SPD Technologies[a]	4 to 59 percent for a double-paned skylight from VELUX
Solar heat gain	30 to 43 percent for a triple-paned window from SPD Technologies	13 to 43 percent for a double-paned skylight from VELUX
Maximum power requirement	0.05 watts per square foot required to maintain the high-transmission state	0.2 watts per square foot required when switching
Switching speed	1 to 3 seconds; does not depend on glass size	1.5 to 3.0 minutes for a 5.3-square-foot VELUX skylight[b]
Length of warranty	5 years for a ThermoView residential window	10 years for a VELUX skylight

Notes: a. Data from Architectural Testing Inc., provided by SPD Technologies Inc., Smyrna, DE, www.infinitint.com.
b. Data from customer service at VELUX, Greenwood, SC, 800-888-3589, www.velux-america.com.

Source: Platts; information from SAGE Electrochromics and Research Frontiers [11] director, says the company is targeting a premium of less than $100 with increased production levels.[15] Charles Smith, CEO of window retailer Thermoview, claims that his company's products made with Research Frontier's technology generally cost about 80 percent more than the company's best-quality conventional replacement windows.[16] Thermoview quoted us a retail price of $245/ft^2 for an 8-ft^2 window.

Commercialization should help lower costs by increasing the volume of manufactured product and paving the way for the implementation of mass production. But even with increased production, this will be no slam-dunk. Inexpensive, widely used low-e coatings consist of a series of thin and easy-to-deposit layers, whereas smart windows are composed of thicker and more-complex layers. That will likely make driving down the cost of smart windows a slower, more-difficult process. In addition, there's the cost of wiring and control equipment. We expect that eventually, with increased manufacturing volume, technological improvements in the coating process, and the addition of innovative new materials for coatings, prices will come down, but research and market challenges remain.

For more information, contact Michael Myser, vice president for sales and marketing at SAGE Electrochromics Inc., 507-333-0078, mmyser@sage-ec.com, or Michael LaPointe, vice present for marketing, Research Frontiers, 800-743-4453, lapointe@smartglass.com.

Notes

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September 19, 2003

Lab Scientist Heads Western Carbon Sequestration Effort

Science Partnerships Key for Engineering

- Building for Better Science
- Short Takes
- Als Crystal Images Shed More Light On Protein Synthesis
- Salty Results From Sno
- Windows of Opportunity
- Studying Supernovae from Space
- Violence in the Workplace: Zero Tolerance
- Passionate About Her Profession
- On Being the Guard at the Gate
- Flea Market

Lab Scientist Heads Western Carbon Sequestration Effort

By Lynn Yarris

Larry Myer of Earth Sciences will look at ways to store carbon emissions like those from power plants and industrial smoke stacks.

Larry Myer, a geological engineer and principal investigator with Berkeley Lab's Earth Sciences Division, has spent more than 20 years studying the movement of fluids through rock and how to monitor them. This extensive research experience should serve him well in his new role as director of the West Coast Regional Carbon Sequestration Partnership, which
is part of a nationwide network of partnerships created by the U.S. Department of Energy to investigate different approaches for carbon sequestration.7

"The Bush administration's goal of an 18 percent reduction in U.S. greenhouse gas emissions by 2012 is realistic if we push hard on developing carbon sequestration technologies," Myer says. "For our part, the West Coast partnership will be working to centralize the data that identify and characterize carbon dioxide sources and sinks in the region, and to develop a pilot demonstration project of what we determine to be the best carbon sequestration technology for the region at this time."

Two-hundred-plus years of indus-trialization has resulted in the emission of an enormous amount of carbon dioxide into the atmosphere. Experts predict that atmospheric carbon dioxide concentrations will double from pre-industrial levels by the middle of this century. Although the effects of doubling atmospheric carbon dioxide levels are not entirely understood, the scientific consensus is that serious environmental consequences will result if steps are not taken to curb emissions. The goal of carbon sequestration is to prevent carbon dioxide emissions from reaching the atmosphere by capturing a significant amount at the source, i.e., power plants and industrial smoke stacks, and securely storing it where no environmental harm would be done.

"The West Coast partnership will be looking at two different sequestration strategies, geological sequestration which entails burying the carbon underground, and terrestrial sequestration, which entails storing it in forests and soils," says Myer. "The western region of the United States offers some of the nation's most favorable sites for geologic and terrestrial sequestration strategies. We will also be working with partnerships in the other regions on aspects of carbon sequestration that we all share."

On August 18 of this year, DOE's National Energy Technology Laboratory named seven regional partnerships that include more than 140 federal, state, and private organizations spanning 33 states, three Native American nations, and two Canadian provinces. These partnerships are to play a key role in President Bush's Global Climate Change Initiative. The West Coast Regional Carbon equestration Partnership is led by the California Energy Commission and includes representative organizations from California,

Windows of Opportunity

New facility not only offers great views, but enables researchers to develop energy efficient windows.

By Allan Chen

Eleanor Lee, project manager and scientist, stands beside a set of test windows in the Advanced Window Systems Test Facility.

There's a new building at Berkeley Lab, and it's got a terrific view — with south-facing vistas overlooking the ALS dome and the San Francisco Bay, three rooms full of office furnishings, and windows that darken automatically when prompted by a remote-control system.

The Advanced Window Systems Test Facility was built to test new window technology that will increase energy savings and occupant comfort. "With this facility," says Eleanor Lee, project manager and scientist in the Environmental Energy Technologies Division, "we'll be able to quantify the energy savings and comfort of commercially-available or prototype window systems under realistic sun and sky conditions."

The Switchable Window

One sytem under study uses electrochromic (EC) material to switch windows from a clear state, to a tinted blue state, which reduces the transmission of visible light and infrared radiation. Typical EC windows can block from 50 to 98 percent of light while maintaining view to the outside, which, on a hot day, can reduce the need for energy-sapping air-conditioning.

Manually operated systems using conventional blinds or shades do not save as much energy as an automated system for managing solar gain and daylight. A study by Lee, Building Technologies Depart-ment Head Stephen Selkowitz, and their colleagues shows that electrochromic systems could save up to 30 percent of the energy used in commercial building perimeter zones, as well as reduce peak electric use compared to conventional window systems. Since commercial buildings spend about $100 billion a year on energy, the potential savings are considerable.

"To get there," says Selkowitz, "we need to solve a number of problems. One of them is designing a solution that integrates the windows and other energy-saving systems in the building using control algorithms."

Measuring the Indoor Conditions

The facility's three rooms are currently outfitted with electrochromic windows from different manufacturers. Sensors placed throughout the rooms measure temperature and light levels, as well as energy used to cool, heat, and light each test room. Computers continuously record this data, along with the percentage of light transmittance, which will change according to the external conditions and the computer algorithm controlling the windows.

By working closely with the EC window industry, researchers can ensure the tests yield information that is accurate, objective and useful to building owners, architects, engineers, and other stakeholders, thereby moving this emerging technology closer to market adoption.

Integration the Next Stage in Window Research

The EC window research is just the latest in a long history of energy-efficient windows research at Berkeley Lab dating back to the early 1980s. "We pioneered the development of low-emissivity window coatings with our partners in the window industry," says Selkowitz. "The windows we are testing today use energy-efficient coatings that reduce solar heat gain. Windows with low e-coatings have saved billions of dollars in winter heating energy costs, and have penetrated more than 50 percent of the annual sales in the residential window market."

The EC windows work is part of a larger effort to combine the most advanced individual technologies into an integrated system that saves far more energy than the components working in isolation.

"System integration allows us to get cost and energy savings from many avenues," explains Selkowitz. "Because the windows reduce the peak cooling load, the office building can use a smaller, less expensive chiller. More daylighting reduces the need for artificial lighting. This lowers energy costs to the building's owners, as well as the utility, by redu-cing the generating capacity they need to provide under peak conditions, or the quantity of peak power they need to buy wholesale from the grid during especially hot days."

Limited EC window tests have already started this summer. The testbed is expected to be fully operational by October.
This research is being funded by the DOE and the California Energy Commission. Private-sector partners include SAGE Electrochromics and Wausau Window and Wall Systems. The facility was built with the industrious help of Chuck Taberski and his Small Projects Group in Facilities.

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Studying Supernovae from Space

By Paul Preuss

The remarkable discovery that the expansion of the universe is accelerating, announced early in 1998 by the Supernova Cosmology Project (SCP) and the competing High-Z Supernova Search Team, was based on comparing the brightness and redshifts of dozens of Type Ia supernovae — almost all of them observed from the ground. The supernova search is now moving into space.

Looking through dust in galaxies can make supernovae appear dimmer, but dust also makes their light redder -- just as dust in our atmosphere makes sunsets appear red. (Galaxy image: 2MASS, with simulated SN)

Early this week the SCP announ-ced results from a set of 11 distant Type Ia supernovae studied entirely with the Hubble Space Telescope (HST). Images of supernovae obtained from airless space are potentially much sharper and provide superior measurements of brightness than are possible from the ground.

The HST repeatedly sampled the light curves and spectra of these 11 supernovae, starting before their maximum brightness and continuing until the explosions had faded away. This makes for “a strikingly beautiful data set,” says the SCP’s Saul Perlmutter, “the largest ever studied exclusively from space.” The data analysis was led by SCP member Robert A. Knop, formerly of Berkeley Lab, now assistant professor of physics and astronomy at Vanderbilt University in Nashville, Tenn.

Because of their brightness and similarity, Type Ia supernovae are the best “standard candles” for measuring the distance to far-off galaxies. Anything other than distance affecting their brightness could throw those measurements into doubt, however. One possible cause of dimming, known to astro-nomers as “extinction,” is dust.

“The HST data provide a strong test of host-galaxy extinction,” Knop says. If dust in a galaxy were to absorb and scatter a supernova’s light, it would also redden that light, much as our sun looks redder at sunset because of particles in the atmosphere. But, says Knop, the HST data show no anomalous reddening with distance: the supernovae “pass the test with flying colors.”
The new study serves a broader purpose, eliminating some of the theoretical schemes that have proliferated to explain the mysterious whatever-it-is that goes by the name “dark energy.”

The first attempt to explain dark energy invoked Einstein’s “cosmological constant,” a term — symbolized by the Greek letter lambda — he had introduced into general relativity under the mistaken impression, shared by scientists at the time, that the universe is static. In 1929, Edwin Hubble found the universe was not static but expanding. Einstein happily abandoned the cosmological constant. But 70 years later, with the discovery that expansion was accelerating, lambda came back strong.

“For the cosmological constant, the vacuum — space itself — possesses a certain springiness,” says Eric Linder, a cosmologist at Berkeley Lab and director of the Center for Cosmology and Spacetime Physics at Florida Atlantic University. “As you stretch it, you don’t lose energy, you store extra energy in it just like a rubber band.”

Unfortunately the most obvious source for lambda’s stored energy is quantum theory’s energy of the vacuum, so much more powerful (10 to the 120th!) than what’s been observed for lambda, says Linder, that “if this were the dark energy it would have brought the universe to a swift end, a miniscule fraction of a second after it was created in the big bang.”

True to its name, the cosmological constant doesn’t change over time: stored energy increases smoothly as the universe’s volume increases. In other theoretical explanations, dark energy can change with time. “Quintessence” is a sort of universe-filling fluid that acts like it has negative gravitational mass. The new HST supernova results, however, discourage at least the simplest models of quintessence.

Quite different “topological defect” models attribute dark energy to defects created as the early universe cooled. Some of these explanations are also ruled out by the HST supernovae study.

Internet-Based Control Systems for Building Energy Efficiency

Contact: Allan Chen, a_chen@lbl.gov

Developing internet-based control systems to improve the energy efficiency of buildings is one of the key elements of the recently concluded High-Performance Commercial Buildings Systems (HPCBS) research program Energy Commission. This article, the second i concentrates on lighting.

"Previous research here taught us that lighting consumption in a variety of ways," says resea... Environmental Energy Technologies Division (EETD). Rubinstein leads a project to improve energy efficiency through flexible control systems that make optimum use of natural lighting.

Letting the sun shine in on energy use

The window office — that most coveted of office spaces in the modern commercial building — is also a naturally energy-efficient office, because the occupant needs less electric lighting when sunshine streams in. Most of us prefer natural light to artificially created light anyway, one reason these offices are so desirable.

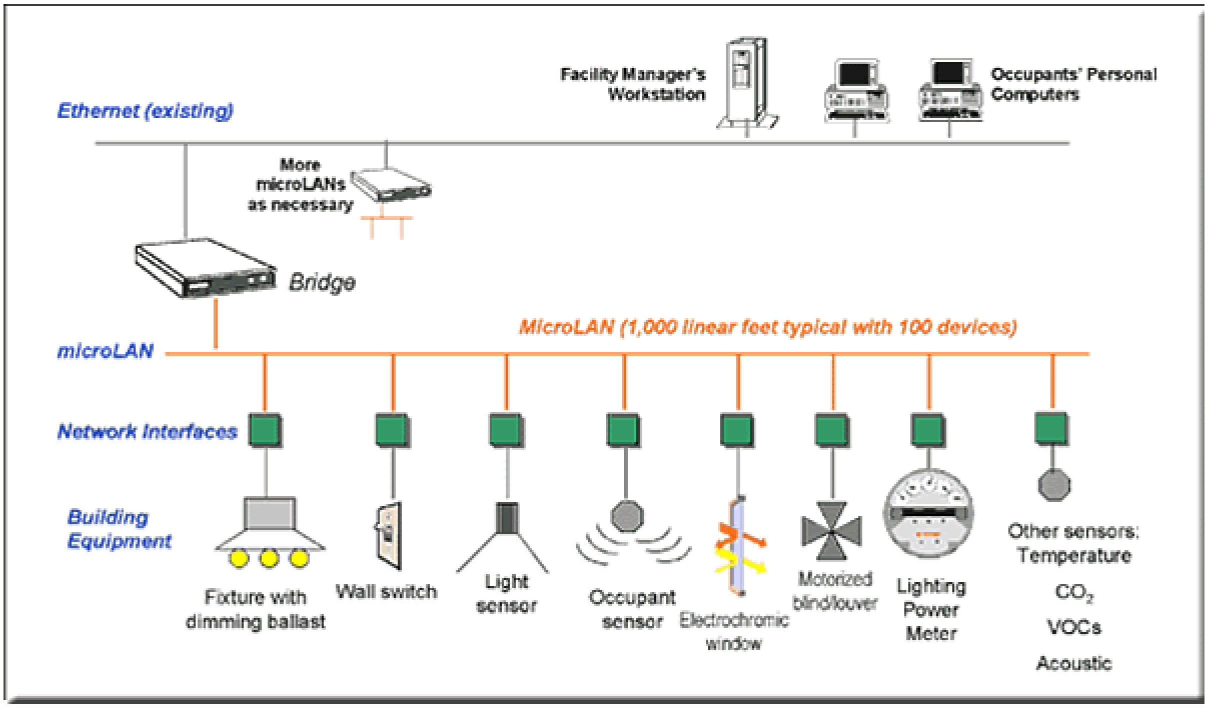
In California, 40 percent of the electricity used by commercial buildings is consumed by electric lighting, the largest single load in these buildings. Throughout the rest of the country, in spite of variations in climate that make heating a larger overall piece of the pie, lighting always uses a substantial percentage of building electricity.

If architects and engineers designed buildings to use daylighting as an integral part of their lighting system, lighting energy use could decrease substantially. But while there has been much progress in the last 20 years in improving the efficiency of electric lights, bringing daylighting into the fold as an energy efficiency strategy has been more difficult.

"It requires careful integration of lighting and window systems, architectural design that recognizes the importance of daylighting, and a control strategy for turning down electric lights automatically as natural light levels increase," says Stephen Selkowitz, head of EETD's Building Technologies Department.

Of course architects do design buildings that bring in more daylight than the sunless canyons of downtown might suggest, with their massive, blocky structures with deep interiors. Unfortunately systems that automatically dim electric lights as daylight increases are expensive to purchase and install. And because these systems also require careful commissioning to operate efficiently, achieving sustainable energy savings has been an elusive goal.

"We know we can use photosensors to integrate daylight and electric light — and occupancy sensors and scheduling to reduce lighting of unoccupied spaces," Rubinstein says. "A third strategy is giving occupants control of their local lighting. Together these three methods can reduce lighting energy consumption substantially, even compared to a state-of-the-art, efficient lighting system with electronic ballasts."



IBECS is a practical networking system that takes advantage of a building's existing IT infrastructure to control off-the-shelf lighting components and other building equipment through the internet.

Rubinstein, his colleagues Eleanor Lee, Dennis DiBartolomeo, Jim Galvin, Judy Jennings, and Pete Pettler of Vistron, a private-sector partner in the project, set out to develop IBECS, an "integrated building equipment communications network" that would allow building lighting and envelope systems to respond automatically to changes in occupancy, daylight levels, and energy costs — while at the same time giving occupants more control over their workspace environment. Their goal is to achieve, by 2015, lighting-related electricity-consumption savings of 59 percent in new construction and 43 percent in major retrofits.

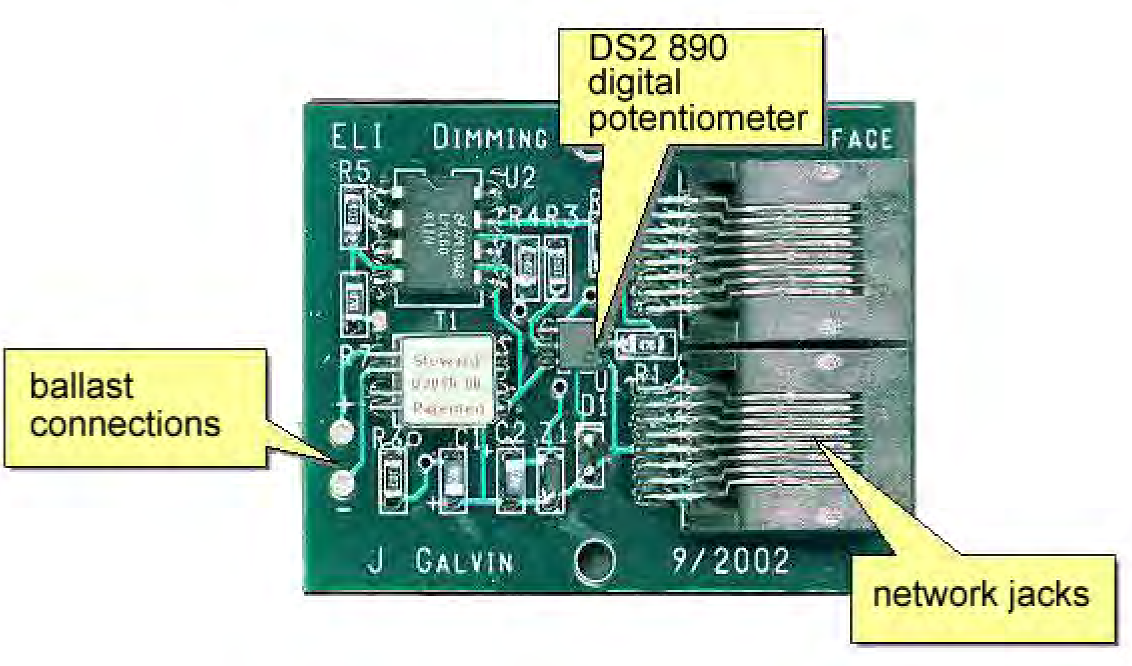
In developing the IBECS network, LBNL researchers applied recent developments in networking techology known as embedded device networks. Microchip manufacturers can now produce embedded devices that incorporate a microprocessor, unique IP address, controller, and simple local-area-network communications at a very low cost per control point. These devices are "embedded" into electronic components like lighting ballasts, which adds a modicum of intelligence to components while allowing them to communicate digitally over a simple network. The IBECS project applies a general-purpose embedded device network from Dallas Semiconductor/MAXIM to building lighting and envelope controls.

"By designing IBECS so that it works with existing products, such as dimming ballasts, it is much easier for lighting manufacturers to adopt the technology to their advanced product lines," says Rubinstein, so he and his team developed the IBECS network to be compatible with existing lighting and envelope components. In addition to hardware development, the researchers worked on control algorithms that would manage the process of taking input from photosensors and deciding when to dim lights, and by how much.

Another area of the work, led by Berkeley Lab's Eleanor Lee, focused on daylighting. Her group used the IBECS networking and control devices to develop a system that allows facilities operators and end-users to control motorized shades and switchable, variable-transmittance, electrochromic windows — an advanced window now in commercial development that darkens and lightens when a small electric current is applied.

IBECS for Lighting Control

"We developed network control hardware," says Rubinstein, "and we built a working system in our office building at Berkeley Lab to test it out." Rubinstein and Pete Pettler of Vistron developed IBECS ballast network interfaces for controlling dimming ballasts (part of fluorescent lighting systems) from the network, an IBECS-enabled wall switch to fit in a standard wall box, provide bi-level switch control, and an IBECS-ready environmental sensor capable of measuring key environmental variables — occupancy, light level and temperature.



An IBECS ballast/network interface incorporating a digital potentiometer dims a 0- to 10-volt ballast over the ballast control circuit.

Rubinstein and his team tested the system successfully in a fully-configured IBECS network installed in a building at Berkeley Lab. The demonstration network includes all the IBECS-compatible technologies they developed for lighting, automated shades and Venetian blind systems, sensors and power measurement. Office workers can control their overhead lights and motorized blinds by internet. The network is a demonstration site for potential industrial partners to evaluate the technology. Potential partners will be able to observe the system's performance using a secure web link.

Above: An IBECS addressable power switch, embedded in a standard wall switch, allows an operator to turn the switch off remotely through IBECS.

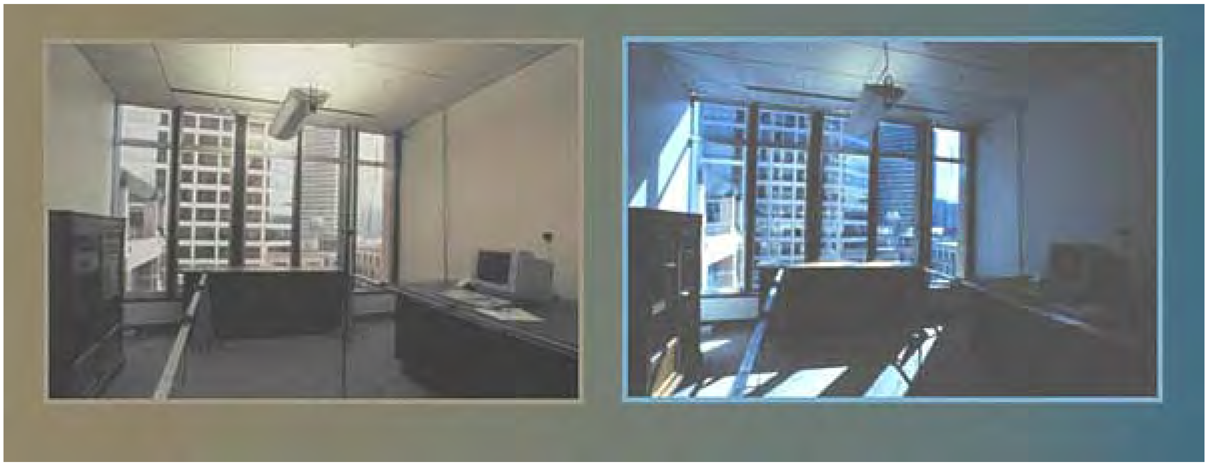
"Adding digital smarts to analog electronics products has been a mainstream business goal for many companies in this field. IBECS technology presents new business opportunities, markets and employment potentials for these companies," says Rubinstein.

The team is working with two ballast manufacturers who have already decided to use IBECS technology in their products. A digital-lighting-network products manufacturer will embed the IBECS ballast network interface in their network connector, and another firm will put IBECS technology in occupancy sensors and daylight control photosensors.

A prototype workstation multisensor measures light levels, temperature, and occupancy, and sends digital data to the IBECS network.

IBECS for Daylighting

Eleanor Lee and Dennis DiBartolomeo applied the IBECS components to controlling dynamic window systems for better lighting-energy efficiency. The networked control technology can regulate direct current-motorized Venetian blinds or roller shades, alternating current-motorized blinds or shades, and electrochromic windows. The first full-scale demonstration in the U.S. of an integrated electrochromic window and dimmable fluorescent lighting system was conducted in a federal office building in Oakland, California, with more tests continuing in a new laboratory at Berkeley Lab.

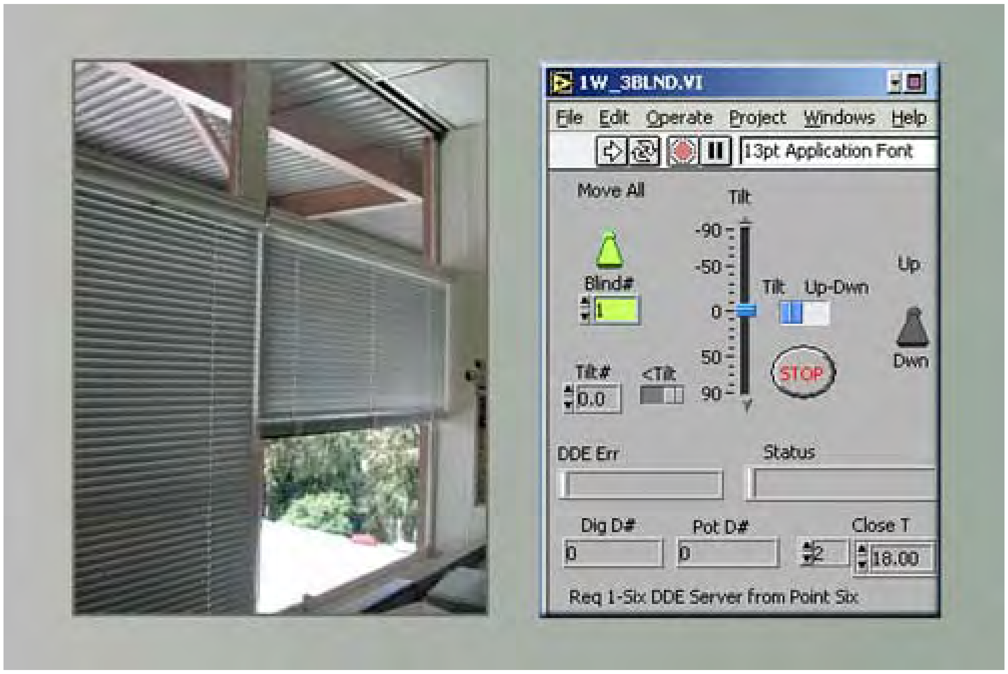


Interior view of test room on a partly cloudy day. The electrochromic windows are in the clear state under diffuse light conditions (left). When sun enters the window, the electrochromic switches within five minutes to its fully colored state (right).

"The commercial prototype electrochromic window and lighting system reduced total energy use significantly," according to Lee. "Our monitored study proved that perimeter zone daily lighting energy use can be reduced by 6 to 24 percent when compared to a standard window transmitting 11 percent with the same daylighting control system. Simulations indicate that total primary energy use" — cooling, heating, and lighting energy — "can be reduced by 14 to 30 percent in all climates compared to advanced spectrally-selective, low-emissivity windows with no daylighting controls in a typical commercial office building. Bench-scale testing also showed that the electrochromic IBECS network interface operated reliably."

Electrochromic windows and lighting systems are controlled in real time to meet an illuminance range and to control solar heat gains and glare. (A) On a cloudy day, the electrochromic window is at its maximum transmission level, and the lights are at minimum power. (B) When the sun comes out from behind a cloud, the window starts to darken to control solar heat gains and glare. (C) After about five minutes of sunshine, the electrochromics are fully darkened and the electric lighting has been increased slightly to provide sufficient interior light.

The team also successfully tested the IBECS interface on motorized Venetian blinds. Using an off-the-shelf software package, they created a virtual control panel from which they could control the tilt, raise and lower functions of the blinds on west-facing windows in an open-plan, occupied office. The system has been working reliably for more than a year.



A Venetian-blind system at a Berkeley Lab office building is equipped with a "virtual instrument" panel for IBECS control of blinds settings.

Reducing Energy on Demand

Ultimately, the tools developed in this research will go beyond saving energy — they could also help building operators respond to electricity grid emergencies, and to money-saving opportunities when energy costs are high. Many states, including California, now have or are looking seriously at real-time electricity pricing, to reflect the true cost of generating power as demand rises and falls throughout the day.

"Building operators, among others, will be able to use this technology to reduce their power consumption when the real-time price of electricity starts to rise," says Rubinstein. They can also respond quickly to shut down energy-consuming equipment when the electricity grid is threatened by outages or other reliability problems."

If IBECS technologies are installed in 20 percent of available building stock in California, and assuming that the energy saving is about 40 percent, the savings potential to California businesses could be 2.4 Terawatt-hours(trillion watt-hours)/year, or $250 million in avoided energy costs. For the U.S. as a whole, although technical estimates are not available, the savings could be an order of magnitude higher.

Personal control of lighting in a worker's individual space also makes the office a more pleasant place — it might reduce the number of complaints building staff have to deal with, and free up their time for long-term maintenance. Finally, the researchers believe that writing control software for building systems is a frontier industry that could generate new software jobs.

In the next issue of Science Beat, the third and final article in this series will examine the results of research on improving the air quality and energy efficiency of temporary classroom structures found in schools throughout the country.

Additional information

- More on High Performance Commercial Building Systems
- More on networked lighting controls
- More on daylighting and electrochromic windows

Top

Chameleon windows

Haven't shown their true colors yet

By Bill Kirtz

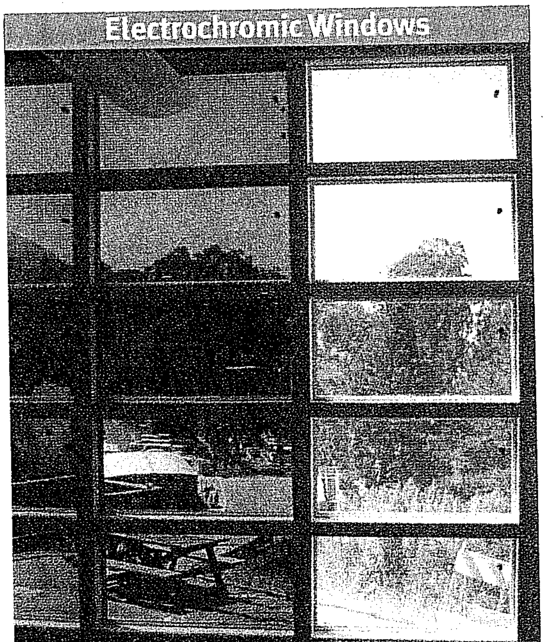
Everyone loves the potential of electrically switchable "smart glass," but some question whether it can be produced cheaply enough for large-scale commercial use.

A window system that changes its transmission when exposed to sunlight can certainly save consumers billions on peak energy costs. The key will be to produce an affordable, reliable and durable product, and the stakes are high.

Fifteen years ago, the average American home had 12 windows, according to the National Association of Home Builders of Washington, DC. Now, the average home has 16 windows and upscale houses of 4,000 to 5,000 square feet have at least 20.

As rival systems battle for funding and industry support for this growing market, micro-thin, low-emissivity coatings remain the energy-efficient choice for the estimated 20 billion square feet of flat glass produced worldwide each year. They reflect heat, sending it back where it came from, and they boost the thermal quality of insulating glass units, helping homes to stay warmer in winter and cooler in summer.

Electrochromic Windows



More than 40 percent of newly installed windows are estimated to have low-emissivity coatings, and low-e products are expected to dominate the market in the future.

Glass designs today can give great solar heat-gain numbers or high light-transmission numbers. What isn't available is a dynamic glass that provides high light transmission on cloudy days and low light transmission on sunny days, while controlling solar heat gain and providing a view. Besides the view, switchable glass has the advantage of using daylight and cutting peak demand, thus saving energy and improving solar heat control.

A 2003 study by Lawrence Berkeley National Laboratory staff scientists in Berkeley, CA, concluded that during the last 15 years, low-e and other technological improvements significantly improved American windows' energy efficiency. But, the study adds, interest in zero-energy homes dictates a new generation of window products. Windows with dynamic solar heat-gain properties offer significant potential in northern and central climates, the study says, while windows with very low-static heat gain offer the most potential in southern climates.

In closely watched trials, SageGlass electrochromic glazing tests continue in a Houston home, a Long Island skylight and in model offices in Oakland, CA. The goal: to demonstrate durability and efficiency so Sage, of Faribault, MN, can work with glass and window manufacturers to create a product for widespread, and particularly commercial use. The data isn't in yet.

Sage's "switchable" windows darken or lighten with a push of a button and control the flow of visible light and solar heat in homes, offices, auto-

The author is professor of journalism at Northeastern University in Boston.

PEREGO SOLERA - Edson Evers & Associates

mobiles and other places. Consumers can block all light or just some by turning a knob, creating huge savings on heating, cooling and lighting costs.

Currently, electrochromic glass is used in small-scale applications, such as rearview mirrors. Mike Myser, Sage vice president for sales and marketing, says the technology would pay for itself within two to three years if used in large applications.

The company has won several Small Business Innovation Research awards through the U.S. Department of Commerce, the Department of Energy, the National Science Foundation and the Department of Defense. It has passed several DOE tests, and is the first to receive DOE approval for durability.

The full-scale window tests feature windows manufactured by Pilkington North America of Toledo, with two identical side-by-side offices: one with manual controls and the other with automatic controls. Eleanor Lee, manager of the project at the Lawrence Berkeley National Laboratory, noted that the DOE and the California Energy Commission co-sponsored the three-year test to "accelerate" the U.S. market for electrochromatics use.

She says the trials are so far very preliminary, and estimates that it will be five to 10 years before electrochromic technology will be in wide use. Nevertheless, Lee predicts "significant energy savings" in residential and commercial use. "Last summer, we measured significant light energy savings [that] varied day to day depending on weather. We have proved that the concept can work."

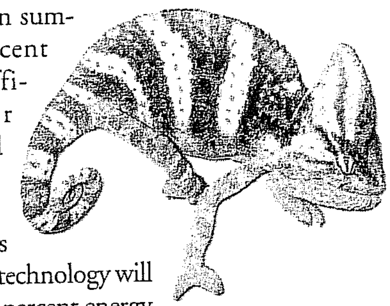
Tests so far show that people prefer automatic controls to static windows, Lee says. "They like windows to switch by themselves. You'd think it would be a bit of 'Big Brother' [controlling people's every movement], but that's not been the case."

Expense is still a factor. Sage windows will have a premium cost when first introduced to the marketplace, driven primarily by volume and production related issues. But the company asserts that as product demand grows and production volumes increase, the price of the windows will be about the same as today's higher end windows with shading systems.

Electrochromically Speaking

SageGlass electrochromic glazing consists of five thin-film ceramic layers coated directly onto glass. The solid-state design is formed in much the same manner as low-emissivity glazing. Sage officials claim that EC glazing provides the energy saving and comfort benefits of low-emissivity glass while delivering the special features of intelligent, variable sunlight and heat control, such as variable tint control. They say widespread marketplace adoption of efficient switchable glazing requires this combination.

High-performance low-e glass is 41 percent more energy efficient in summer and 35 percent more energy efficient in winter than standard dual-pane glazing, Sage officials say. DOE officials estimate that this technology will result in up to 28 percent energy savings for cooling, 31 percent heating energy savings and 23 percent peak demand energy savings compared to low-e and tinted low-e windows.



Reluctant to disclose Sage's price structure, Myser cites surveys showing that 13 percent of architects would be willing to pay more than $25 a square foot for electrochromic glass, 65 percent would pay more than $15 and 91 percent would pay more than $10.

Durability is always an issue in developing technology. The glass in residential windows today is typically warranted for up to 10 years, and the expectation is that the glass units will perform well beyond that.

Observing that electronically tinted windows will need to meet these industry expectations, Sage officials claim electrochromics durability has been proven during five years of testing samples of its prototype windows at third-party facilities, in-house and at government laboratories. The prototypes have shown lifetimes of more than 100,000 switching cycles with no noticeable degradation: 10 cycles a day for 27 years, or two cycles a day for 137 years.

Stephen Selkowitz, head of the Building Technologies Department at the Lawrence Berkeley lab, notes that the facility has been working 25 years on energy-efficient glazing. He predicts that more national attention will be focused on high energy costs. Since utility economists look at pricing power on a highly variable basis, Selkowitz says, "façade control would be more important." Among the potential benefits he sees in "smart glass" technology is not having to install shading systems.

"We're completely convinced of the benefits of smart technology; convinced some type of these windows are the way to go." he says, but, "Sage must demonstrate real effects. Manufacturers don't have credibility, they have an axe to grind. So our purpose is to be an objective third party."

Ren Anderson, residential project manager of the National Renewal Energy Laboratory at Lakewood, CO, calls the Sage experiment "exciting."

"There's broad interest in electrochromics from the window industry," Anderson says. "We're starting to see switchable energy with large-scale manufacturing capacity. Before it was just foot-by-foot. Now we're starting to see full-size windows."

Anderson names one "big issue" with Sage's technology: reducing "technical support barriers. The next question is really up to the marketplace, [to get] capital investment to bring costs down. This is out of our control. We hope it takes the market by storm but we'll see what happens. The price trends of other technologies' costs have fallen with time, [but] how far and how fast costs go down depends on the demand for product. It has to be a commodity before it gets a large share of the market."

Joe Wiehagen, project engineer at the National Association of Home Builders, says he sees "potential for some very good cost trade-offs" with Sage technology.

"We wouldn't be going there if we didn't think we can get there," he says. "The Sage product can work, but we need some more product development and evolution to define how much. There are lots of huge questions as to what would drive consumers; the convenience factor could drive it more than we know right now."

Advice From the Field

Wausau Window and Wall Systems of Wausau, WI, a supplier of aluminum windows and window-wall systems, provided specimens for test beds and has installed various manufacturers' electrochromic glass. Steve Fronek, Wausau's vice president for research and development, says there's certainly a need to build models to recognize operating and installation costs to justify the use of smart window technology.

"The pace of commercialization depends on market forces which will drive prices down," Fronek says. "It's an extremely promising technology [but it] requires much closer integration between all facets of the job than conventional windows. It will need a new design discipline; all members of the design and construction team must work together much more than in conventional glazing."

More confident is Richard Wind, general manager of Four Seasons Solar Products' commercial division, who had been working with Sage to install the world's first commercial electrochromics skylight. His firm, located in Holbrook, NY, is one of the country's largest sunroof manufacturers, and sees restaurants and offices as among those customers eager to change lighting with the push of a button.

"We're confident Sage will get costs down to be commercially successful," he says. With tests continuing at the Westchester County, NY, installation, he says, "there is a potential market for this. Otherwise, we wouldn't be spending our time."

Brian Binash, president of Houston's Emerald Homes, has built two identical homes as a residential field evaluation. He installed Sage glass in one and conventional glass in the other, and will measure the energy usage differences. Here, too, tests are continuing and no results are currently available.

Binash says he was "eager to get into cutting-edge technology in building energy-efficient homes. We think the technology has potential [but] we're not privy to [Sage's] cost information. "So far, so good,"says Craig Dudley, Emerald's operations director. "It will be interesting to see how it will turn out."

Unmet Promise of Yet Another Coating

Reporting in the October issue of the Journal of Materials Chemistry, University College London researchers reveal the development of an intelligent window coating that, when applied to the glass of buildings or cars, reflects the sun's heat.

While conventional tints and coatings block heat and light, this coating allows visible wave lengths of light through, but reflects infrared light when the temperature rises over 29 degrees Celsius or 84 degrees Fahrenheit, the researchers claim in an August press release. Wave lengths of light in this region of the spectrum cause heating, so, blocking infrared reduces unwanted heat from the sun, the researchers write.

Made from a derivative of vanadium dioxide, the coating's ability to switch between absorbing and reflecting light means occupants benefit from the sun's heat in cooler conditions, but when temperatures soar, room heating is reduced by up to 50 percent.

Professor Ivan Parkin of UCL's Department of Chemistry and senior author of the paper, writes, "Technological innovations such as intelligent window coatings really open the door to more creative design. The current trend toward using glass extensively in buildings poses a dilemma for architects. Do they tint the glass, reducing the benefit of natural light, or face hefty air conditioning bills?

"While the heat-reflective properties of vanadium dioxide are well recognized, the stumbling block has been the switching temperature. It's not much good if the material starts to reflect infrared light at 70 degrees Celsius or 158 degrees Fahrenheit. We've shown it's possible to reduce the switching temperature to just above room temperature and manufacture it in a commercially viable way," Parkin writes.

Vanadium dioxide's properties are based on its ability to alternate between acting as a metal and semiconductor. The switch between reflecting or absorbing heat is accompanied by a small change in the structure of the material, where the arrangement of electrons changes. Vanadium-vanadium bonds are stable below the transition temperature that "locks" the electrons and prevent conduction. These vana-

Lisa Gonzalez, president and chief executive officer of Design Alternatives in Santa Clara, CA, likes the technology, but is skeptical about Sage's cost claims. She has noted that switchable glass can cost hundreds of dollars per square foot. She has tried to use SageGlass, she says, but finds it extremely expensive and hard to sell to potential customers. "If it were twice the regular cost, that might be price point. It's ideal to be able to push a button and avoid motorized screens."

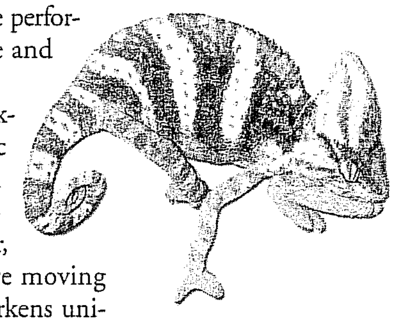
Suspended Particle Devices

Gonzalez' views agree with those of Sage technology rival Mike LaPointe, director of sales and marketing of Research Frontiers Inc. of Woodbury, NY, a developer of suspended particle device windows for more than 20 years. He terms Sage's two- to three-year payback estimate "wildly optimistic."

LaPointe says electrochromics' technology "works really well" in small installations such as rearview mirrors, but voices skepticism about whether it can ever get large-scale prices on a par with current low e-prices.

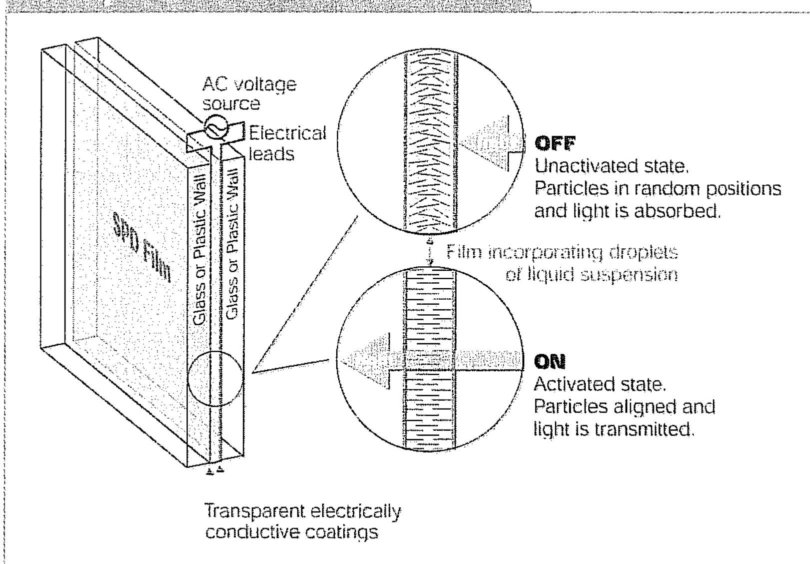
"Sage's panel test results look decent," he says, but "the problem is to get to the cost point, and that's almost impossible."

Suspended particle device windows cost about three times more than standard glass windows; a 40-inch-square window costs \$3,000 to \$3,500. SPDs use small light-absorbing microscopic particles, or light valves. Its developers claim these advantages over electrochromics: faster response time, darker "off" states, lower estimated costs, more reliable performance over a wider temperature range and lower current drain (see drawing below).



While suspended-particle glazing darkens in less than a second, an electrochromic mirror takes about six seconds to darken and up to 10 seconds to clear. Larger electrochromic panes would be even slower, and tend to darken at the edges before moving inward. A suspended particle device darkens uniformly. Unlike electrochromic glass, which works by containing a material that darkens when connected

Suspended Particle Devices



Source: Research Frontiers Inc., Woodbury, NY

dium-vanadium bonds break above the transition temperature and the electrons are free to conduct electricity, making the material metallic.

Previous attempts to lower the switching temperature have incorporated low levels of elements such as tungsten, molybdenum, niobium and fluorine. These lower the transition temperature by supplying electrons into the material, which makes the metallic structure more stable.

By varying the levels of tungsten, the researchers were able to show that the optimum concentration was 1.9 percent. To make the coating cheaper to manufacture, a method of laying down the coating during glass manufacture was necessary.

Troy Manning, lead author of the study, now based at the University of Liverpool, explains: "For the glass manufacturing industry, one of the most important coating methods is atmospheric pressure chemical vapor deposition, because it allows the film to be deposited during the float-glass manufacturing process and is performed at atmospheric pressure, so no high-cost vacuum systems are required.

The research was funded by the Engineering and Physical Sciences Research Council.

Professor Parkin adds: "The next step in getting the coating to market is to investigate how durable it is. Ideally, because it's laid down at the point of manufacture, you want it to last for the lifetime of the window, but looking round you see many windows that date from the Victorian era, so we need the coating to last for over 100 years.

"Another consideration is the color of the coating," Parkin says. "At present it's yellow or green, which really isn't attractive for windows. So we're now looking into color suppression."

Mitch Edwards, manager of applications engineering at Guardian Industries Corp., in Carleton, MI, says that a Guardian scientist has done some work using vanadium as a component of a thermochromic film and found that while there were some slight positive thermal effects, the vanadium caused about a 10 percent drop in visible transmission. According to the Guardian scientist, the major drawback to the use of vanadium was a deep yellow transmitted color, Edwards says.

Sources

SageGlass: Mike Myser, vice president for sales and marketing, Sage Electrochromics Inc., 2150 Airport Drive, Faribault, MN 55021, 507/333-0078, info@sage-ec.com, www.sage-ec.com/pages/intro.html

Research Frontiers Inc.: Mike LaPointe, director of sales and marketing, 240 Crossways Park Drive, Woodbury, NY 11797, 888/SPD-or 516/364-1902, info@SmartGlass.com, www.refr-spd.com/index.html

Pulp Studio Inc.: Bernard Lax, president, 3211 La Cienega Blvd., Los Angles, CA 90016, 310/815-4999, sales@pulpstudio.com, www.pulpstudio.com

to a current of neutrally charged ions, a suspended particle device draws no current when tinted.

Research Frontiers, based in Woodbury, NY, granted four new licenses—bringing its total to 33—last spring: to Pilkington, to produce lamination and other services; to SmartGlass Ireland Ltd. of Dublin, to make and sell architectural window products; to Prelco, to make and sell architectural, residential and commercial windows, skylights and bus and train windows and sunroofs in Canada, Mexico and the United States, and to DuPont of Wilmington, DE, to sell architectural and auto window products worldwide.

Robert Saxe, chairman of Research Froniers, said at the company's annual meeting in June, "Unless and until one or more large orders are received by our licensees," it's unlikely that the company he founded in 1965 would be profitable. If one or more licensees get a thousand unit orders, he said, "this will be a clear signal that industry sees real merit in our SPD products."

Liquid-Crystal Technology

Another electronically switchable option uses liquid-crystal technology. A liquid-crystal sheet is bonded between two layers of glass. Once switched on, the voltage rearranges liquid-crystal molecules to let parallel light pass through the glass. When switched off, the molecules disperse light.

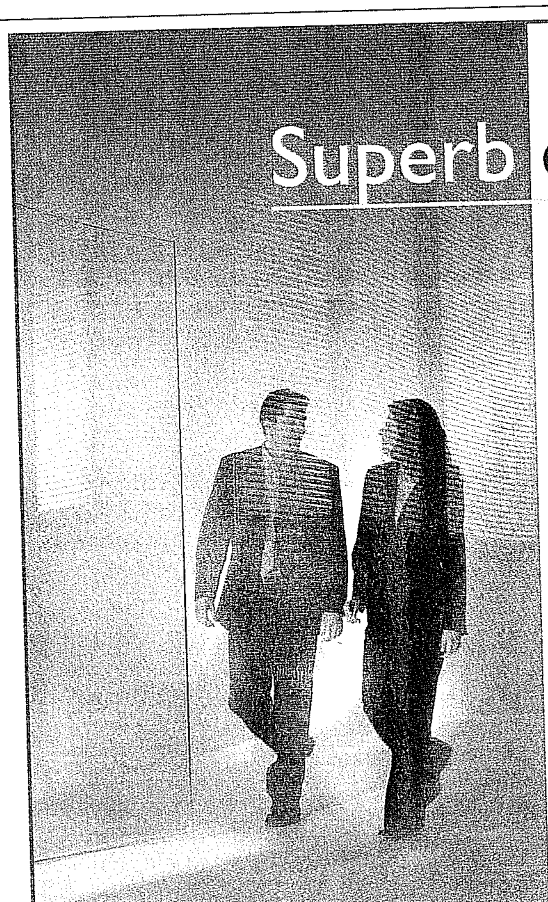
Bernard Lax, president of Los Angeles' Pulp Studios, manufacturer the liquid-crystal interlayer, says that this energy-efficient technology is primarily used in privacy glass. Pulp Studios specializes in interior work for high-security areas, laboratories and Hollywood sets.

Lax says that liquid-crystal technology is "unique but not new. In fact, scientists have been experimenting with liquid crystals ever since they were discovered in 1888. A lot of people have gone in and out of the business; they learned that that this is very much a niche business."

Striving to widen the liquid-crystal niche is Polytronix Inc.'s Jianlin Li, vice president of engineering at the Richardson, TX, facility. He uses a polymer-dispersed, liquid-crystal technology, patented by Ohio's Kent State University, where Li received his doctorate. A switch changes the view from cloudy white to optically clear.

Polyvision glass is now used in interior settings such as conference rooms, prisons and intensive-care areas. Li says the company is developing plans to work with a foreign consortium on other uses.

Nobody doubts that the various competing smart-glass technologies can lower costs; the question is whether these expenses can offset the extra glazing costs.



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SMART GLASS

Private and Cool

Glass partitions us from other people and the elements, while letting light through. But that transmission can be a problem if we want to have privacy or to block the sun's heat. Smart glass can help, letting us change the properties of windows on demand.

At the push of a button, liquid-crystal glass can rapidly transform from clear to frosted, turning a see-through conference room wall, shower stall or ambulance rear window into a visual barrier [*see illustration, top far right*]. No space-consuming or dirt-collecting shades, curtains or blinds are needed. This "privacy glass" is impossible to see through because it scatters incoming rays, yet the diffusion fills the interior space with natural light.

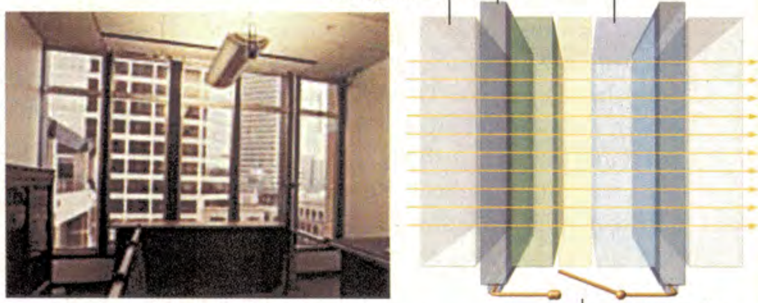
With electrochromic glass, applying a voltage for several seconds to several minutes darkens panels, blocking light [*see illustration, top right*]. When used as windows for buildings, they shade interiors and cut cooling costs. Inhabitants can control the degree of tint, which remains after the power is turned off.

Another option is glass containing suspended particles, which function somewhat the way liquid crystals do. Windows with thermochromic gels that turn white or colored when solar heat surpasses a threshold temperature can cut interior cooling demand, too.

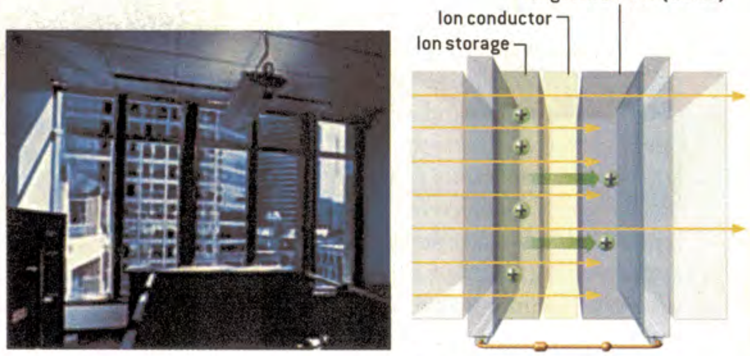
Privacy glass is not more ubiquitous because of the expense, which can be \$100 to \$130 a square foot versus \$10 for standard tempered glass. But customers are becoming more intrigued: "They're using it not just for conference room and bathroom walls but in skylights that block UV [ultraviolet] rays, for privacy between restaurant booths, in bank offices, even for airplane windows," notes Jeff Besse, president of LTI Smart Glass in Lenox, Mass.

The price of electrochromics for energy-efficient buildings may be double that for "low-emissivity" gas-insulated glass, but the larger issue is convincing architects and builders about long-term durability, says Roland Pitts, optoelectronics team leader at the National Renewable Energy Laboratory in Golden, Colo. "The windows must be stable for 30 to 40 years under wide-ranging temperature and solar radiation conditions," he notes, "while switching on and off tens of thousands of times or more." *—Mark Fischetti*

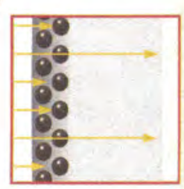
LAWRENCE BERKELEY NATIONAL LABORATORY (*top and middle left*); SMARTGLASS IRELAND LTD. (*top and middle right*); ILLUSTRATIONS BY GEORGE RETSECK



ELECTROCHROMIC WINDOW, when unpowered, transmits light; all layers are transparent.



APPLYING VOLTAGE creates an electric field that drives lithium ions from storage, converting tungsten oxide into tungsten bronze. That layer absorbs ultraviolet and certain visible wavelengths, resulting in a tint. The longer voltage is applied, the darker the tint. Tint remains for long periods after the power is turned off; applying a reverse voltage clears the glass. In an alternative solid-state design, the active inner layers constitute a thin film applied to one pane of glass.



PHOTOCHROMIC LENS is doped with silver halides. The molecules become excited when hit by the sun's ultraviolet rays and then absorb visible wavelengths, cutting glare and darkening the glass. Without UV rays indoors, the lenses lighten.

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In This Issue:

- High-Performance Glazing: Making the Most of Today's Advanced Technologies
- Glazing and Title 24
- Events & Conferences
- About *e-News*
- Training Schedule

Glazing and Title 24

California's Building Energy Efficiency Standards, commonly referred to as Title 24, sets minimum performance requirements for fenestration. In commercial buildings that follow the prescriptive approach to compliance, the 2005 Standards require that windows must have a U-factor no greater than either 0.47 or 0.77, depending on the climate zone.

The relative solar heat gain of the windows must be no greater than the values given in Tables 143-A, 143-B, or 143-C of the Standards. The relative solar heat gain values vary by climate zone, window-wall ratio, and window orientation. For details, download the Standards from **http://energy.ca.gov/title24/2005standards/index.html**.

The window performance data typically provided by glazing manufacturers are center-of-glass U-value and SHGC that do not include effects of the frame on overall window performance. Since 2001, however, Title 24 has required that window performance be evaluated as a whole, including the U-factor that includes frame effects. To help designers calculate the overall U-factor and SHGC of a window assembly, LBNL developed a software program, Window 5.2, which includes a current database of manufacturers' glazing data. It's available for free from **http://windows.lbl.gov/software/default.htm**. ■

High-Performance Glazing: Making the Most of Today's Advanced Technologies

Today's designers can choose from an exciting array of high-performance glazing products. But with so many options available, selecting the right glazing for any given application is more complicated than ever.

If your glazing expertise needs a tune up, a good place to start is the Energy Design Resources design brief, *Glazing* (**www.energydesignresources.com/resource/20**). Another useful resource is the Web site *Windows for High Performance Commercial Buildings* (www.commercialwindows.umn.edu). Sponsored by the U.S. Department of Energy's Windows and Glazings Program, this Web site was developed jointly by the University of Minnesota and Lawrence Berkeley National Laboratory (LBNL).

Both publications emphasize that the best glazing selection for a particular application depends on many variables, including climate, building and window orientation, shading, and how the space will be used. With so many factors in play, it is impossible to provide one ideal glazing specification for all California buildings. Instead, designers should do a whole-building life-cycle analysis for each project that takes into account lifetime building energy consumption, daylighting utilization, and the value of cooling equipment displaced by more advanced glazing systems.

Interior view of the LBNL full-scale test facility with electrochromic windows at three different levels of transmittance: fully colored (left), colored partially (middle), and fully bleached (right). Photo courtesy of LBNL.

In many cases, selecting advanced glazing systems will create a cascade of benefits and savings. For example, glazing that reduces solar heat gain can lower air-conditioning costs. By lowering peak cooling loads, it may be possible to reduce the size of the mechanical system and its components. Smaller chillers, boilers, ducts, and fans could yield a notable reduction in capital costs.

If that advanced glazing also provides high visible transmittance (in combination with adequate glazing area), it can be used to illuminate interior

(continued on page 2)

spaces with daylighting. Automatic controls that switch or dim the electric lights in response to available daylight levels can potentially lower lighting energy use. The only way to thoroughly evaluate the interdependent effects of these measures is to conduct building energy performance simulations.

High-Performance Glazing Today

When it comes to glazing, the term "high performance" refers to a variety of technologies, as described below, that can be used alone or in combination to provide an array of benefits, including lower energy costs, enhanced daylighting opportunities, more comfortable spaces, increased productivity, improved durability, and better security.

Insulated Glazing, Edge Spacers, and Gas Fills

Insulated glazing units are constructed of multiple panes of glass with air spaces between them to improve the insulating value compared to single-pane glazing. Double-pane glazing has been in widespread use for many years; insulated glazing units with three or more panes are also available, and can be cost effective for commercial buildings in the hotter inland California climates.

Edge spacers hold the panes apart. A low-conductance, thermally improved spacer, also called a warm-edge spacer in cold climates, will help reduce heat losses and gains compared to traditional aluminum spacers.

The space between panes, normally filled with dry air, can be filled with a low-conductance gas such as argon or krypton to further reduce heat transfer. Gas fills are usually only justified for buildings that use large amounts of heating or cooling energy.

Low-E Coatings

Adding low-emittance (low-e) coatings can further reduce heat losses and gains in an insulating glass unit. The low-e coating is made by depositing very thin, transparent layers of metals or oxides on the glass. When a low-e coating is added to a conventional double-glazed unit, it provides thermal properties equivalent to triple glazing. Low U-value "superwindows," which are typically a combination of insulated glazing, low-e coatings, edge spacers, and fills, are traditionally used in cold climates but these windows can provide significant energy reduction and be cost effective in hot climates as well.

While conventional low-e coatings are primarily designed to reduce thermal transfer, spectrally selective low-e coatings also have the ability to reflect much of the infrared portion of the solar spectrum while transmitting most of the visible. A spectrally selective low-e glazing will let in more daylight than solar heat gain, and in cold climates has the added advantage of keeping warmth in the building in the winter.

New Options for Highly Insulating Glazings

Manufacturers are developing additional options for highly insulating glazings but most are not yet commercially available. Companies are now offering double-fiberglass glazing assemblies that are filled with a translucent insulation material such as aerogel. This foam-like substance consists of about 4 percent silica and 96 percent air. The microscopic cells entrap air, reducing heat conduction while allowing transmission of diffuse light. Other companies are working on transparent aerogel layers for use between glass layers. Researchers are also pursuing evacuated window technologies; these are insulating window units in which the space between the panes is a vacuum.

Framing Systems

Most glazing systems are held in place in the wall or façade with framing systems. Framing systems for curtain walls are typically aluminum. Aluminum alone is not a good insulator so thermal breaks can be added to the framing system to reduce energy transfer. Manufactured commercial windows have frames that are made of metal, wood, fiberglass, or hybrid designs.

Tinted Glazing

Traditional bronze and gray tinting have fallen from favor because although they slightly reduce solar gain, they greatly reduce visible transmittance, thereby diminishing daylighting opportunities. Today's high-performance tinted glass, which has a light blue or light green tint, offers both higher visible transmittance and a lower solar heat gain coefficient (SHGC). It can be combined with low-e coating to further improve performance.

(continued on page 3)

Events and Conferences

April 4–5, 2006

Ceres Conference 2006
Oakland, CA

Titled "Accelerating Sustainable Governance," this conference focuses on how sustainable governance builds shareholder value and promotes lasting prosperity.

www.ceres.org/events/conference

April 12–13, 2006

Green Construction 2006
San Jose, CA

Conference and exhibition focusing on the design and construction of environmentally friendly buildings.

www.greenconstruction2006.com

April 19–21, 2006

National Conference on Building Commissioning
San Francisco, CA

The commissioning industry's premier conference on how to make buildings work better.

www.peci.org/ncbc

Reflective Coatings

Reflective coatings are made by firing thin metallic or metal oxide layers onto clear or tinted glass. These coatings can provide the lowest solar heat gain, but as with tinted glazing, visible transmittance usually drops more than SHGC.

Plastic Films

As an alternative to triple- or quadruple-pane glass windows, which can be relatively thick and heavy, some manufacturers offer windows with a low-e coated, thin plastic film that is suspended between two panes of glass. This lowers the U-factor while providing favorable optical performance.

Laminated glazing is made by bonding a thin film of polyvinyl butyral (PVB) between two panes of glass to improve durability and safety. It is often used in applications where hurricanes, earthquakes, or bomb blasts are a concern.

Fritted Glazing

Fritted glazing has a baked-on ceramic coating that provides color and patterns. White is the most common color, but gray, black and metallic silver frits should be considered if reducing reflection is a concern. The darker frits can increase heat gain through absorption of solar gains.

Emerging Technologies

Researchers and manufacturers are developing a new generation of switchable glazings that hold out the promise of significant energy savings for commercial buildings. Often dubbed "smart windows," the optical properties of these dynamic glazing materials change as a result of changes in temperature, light, or voltage.

Electrochromic Windows

The most promising of these technologies for windows in commercial buildings seems to be electrochromic coatings, which have the ability to change from clear to a colored transparent state without degrading views. An electrochromic coating consists of multiple layers of very thin films, whose optical properties are controlled by applying a low voltage.

Electrochromic coatings can be used in combination with low-e coatings and insulating glass units to reduce heat transfer. Typical electrochromic windows have an upper visible transmittance range of 0.50 to 0.70, with a lower range of 0.02 to 0.25. The SHGC ranges from 0.10 to 0.50. Very low transmission levels (<0.001) are needed to provide full privacy and eliminate glare. High transmission levels can be used to allow in daylight during overcast periods.

Recently, LBNL completed an extensive field study on prototype electrochromic windows in a full-scale test facility at LBNL. "Electrochromic windows can play a significant role in reducing energy and peak demand in future buildings while delivering improved occupant comfort and amenity," says Eleanor Lee, co-principal investigator of the project, "as long as they are controlled and integrated properly with other building subsystems such as the electric lighting and mechanical systems."

High-performance glazing, as discussed above, can reduce solar heat gain and illuminate spaces with daylight. "Smart glazings," Lee says, "can optimize these interdependent effects in real-time under variable sun and sky conditions. The control algorithm is key to attaining a comfortable work environment and energy savings."

LBNL field data showed that if the electrochromic windows are controlled to maximize energy efficiency, average daily lighting energy savings ranged from about 10 to 45 percent, cooling load savings were 5 to 15 percent, and average peak cooling load reductions were about 20 percent compared to a more conventional but efficient system—a shaded, spectrally selective, low-e window with the same daylighting control system. Savings would be even larger if compared to a conventional code-compliant design. If the electrochromic windows are controlled for visual comfort as well as energy efficiency, these savings might decrease; the degree would depend on how one controls for visual comfort.

In the study, occupants judged the automated electrochromic window system

(continued on page 4)

About *e-News*

Don't miss future issues—to sign up for a free email subscription, please visit **www.energydesignresources.com/enews.php**. Send letters to the editor, suggestions on topics for future issues, or other comments to **admin@energydesignresources.com**.

e-News is published by Energy Design Resources (**www.energydesignresources.com**), an online resource center for information on energy efficiency design practices in California.

Savings By Design (**www.savingsbydesign.com**) offers design assistance and incentives to design teams and building owners in California to encourage high-performance nonresidential building design and construction.

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(continued from page 3)

as significantly more desirable than the reference window (a static high-transmittance window with manual Venetian blinds). Preferences were strongly related to perceived reductions in glare, reflections on the computer monitor, and window luminance. “Since occupants used blinds more frequently with the reference window,” says Lee, “the electrochromic system has the added advantage of providing views out for a larger percentage of the day.” Electrochromic windows, she notes, are expected to yield greatest energy efficiency and peak demand reductions in commercial buildings with large-area windows in hot inland regions of California.

Large-area electrochromic windows and skylights have just been introduced to the market and are available in sizes of up to 42 by 60 inches with on-off switching. Continuous modulation between the fully colored and bleached states is anticipated to be available shortly.

Other Smart Windows

Suspended particle devices are another type of variable-tint windows; however, their long-term durability is not yet proven. Other technologies in the works include photochromic windows that change transparency in response to light intensity, thermochromic windows that change transparency in response to temperature, and gasochromic glazing, which are darkened when diluted hydrogen is introduced into the window cavity. None of these emerging technologies have yet made it to market.

Another new technology is the liquid crystal device window, also known as switchable privacy glazing. In its unpowered state, the crystals are randomly oriented and block sunlight transmission and view; applying an electric field to the film aligns the particles and permits views out. Liquid crystal device windows are already on the market, although their SHGC remains high and considerable power must be used to keep them in their transparent state.

For more information about these advanced technologies, visit the Windows for High Performance Commercial Buildings Web site (**www.commercialwindows.umn.edu**).

Training Schedule

Partial list of upcoming classes. For a complete list, visit each utility’s website.

Date	Course	Time	Location	Units
Mar 7	*Building Commissioning*	8:30AM–12PM	ERC	3
Mar 9	*EnergyPro 4 Nonresidential Title 24 Updates*	9AM–3PM	San Diego	4.5
Mar 9	*Daylighting in Practice—Lessons from the Seattle Better Bricks Daylighting Lab*	9AM–4:30PM	PEC	6
Mar 9	*Basic Lighting for Commercial and Industrial Facilities*	8:30AM–12PM	Temecula	3.5
Mar 14	*Basic Lighting for Commercial and Industrial Facilities*	5:30–9:30PM	Yucaipa	3.5
Mar 14	*The Gas Company’s Energy Efficiency Expo 2006*	8AM–12PM	ERC	0
Mar 14	*Design Strategies for High Performance Glass*	9AM–12PM	CTAC	3
Mar 14	*Identifying and Assessing Common Retrocommissioning Opportunities*	9AM–4:30PM	PEC/ Internet	6
Mar 15	*Title 24 2005 New HVAC and Acceptance Test Requirements*	9AM–4:30PM	PEC/ Internet	6
Mar 16	*Basic Heating, Ventilation and Air Conditioning*	8:30AM–12PM	San Bernardino	0
Mar 23	*Basics of Photovoltaic (PV) Systems for Grid-Tied Applications*	9AM–4:30PM	Oakland	6
Mar 22	*Packaged Unit Heating, Ventilation and Air Conditioning*	8:30AM–4PM	CTAC	0
Mar 24	*Introduction to Life-Cycle Costing*	8:30AM–12:30PM	CTAC	0
Mar 29	*Energy 101*	8:30AM–12PM	Palm Desert	0
Mar 30	*Exceeding Title 24 for Schools*	9AM–1PM	PEC/ Internet	3.5

Training Locations

Location	Explanation	Phone	Website
CTAC	SCE’s Customer Technology Application Center, Irwindale	(626) 812-7537	www.sce.com/ctac
ERC	Southern California Gas Company’s Energy Resource Center, Downey	(562) 803-7500	http://seminars.socalgas.com
Oakland	Oakland City Hall	(415) 973-2277	www.pge.com/pec
Palm Desert	Palm Desert Chamber Building	(626) 812-7537	www.sce.com/ctac
PEC	PG&E’s Pacific Energy Center, San Francisco	(415) 973-2277	www.pge.com/pec
San Bernardino	San Bernardino County Business Resource Center	(626) 812-7537	www.sce.com/ctac
San Diego	SDG&E Century Park	(858) 636-5726	www.sdge.com/construction/ee_commercial_newconst_training.shtml
Temecula	Temecula Valley Chamber of Commerce	(626) 812-7537	www.sce.com/ctac
Yucaipa	Crafton Hills College	(626) 812-7537	www.sce.com/ctac

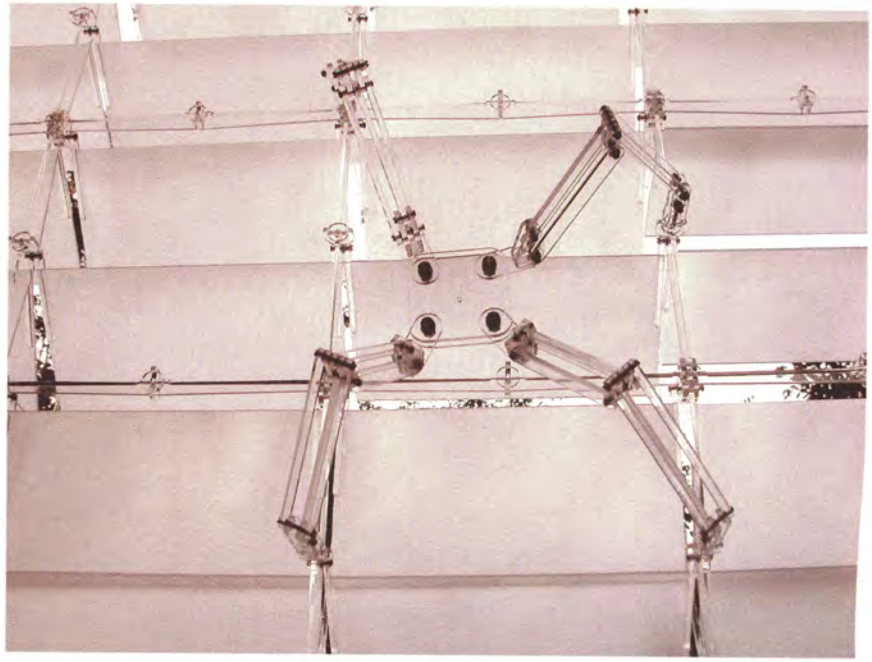
Robo Buildings: Pursuing the Interactive Envelope

IN RECENT PROJECTS, SMARTER BUILDING SKINS AUTOMATICALLY CONTROL DAYLIGHTING, VENTILATION, AND MORE TO BENEFIT OCCUPANTS AND ENHANCE SUSTAINABLE DESIGN QUALITY

By C.C. Sullivan

In an article published in the cyber journal *Technoetic Arts* last year, British architect-academics Stephen A. Gage and Will Thorne describe a hypothetical fleet of small robots they call "edge monkeys." Their function would be to patrol building facades, regulating energy usage and indoor conditions. Basic duties include closing unattended windows, checking thermostats, and adjusting blinds. But the machines would also "gesture meaningfully to internal occupants" when building users "are clearly wasting energy," and they are described as "intrinsically delightful and funny." The authors liken the relationship between edge monkey and human to that of P.G. Wodehouse's Jeeves and Wooster characters. "Jeeves's aim is always to modify Wooster's behavior so that it is more sensible," they write. "And we need all the persuasion we can get to modify our behavior before the planet is severely compromised."

Practicalities of microrobotics aside, this sci-fi-sounding scheme crystallizes the widespread concern informing many recent architectural projects. Increasingly, architects would like to automate their building envelopes rather than leave energy-efficient operation to chance (or harried maintenance engineers). As a result, the critical interface between the interior and the elements is getting more attention—and more animated.



"Edge monkeys" are robots that would close windows, check thermostats, adjust blinds, and "gesture meaningfully to internal occupants" when they are clearly wasting energy.

C.C. Sullivan is a consultant and author who specializes in architecture and technology. He is currently writing a book on interactive building envelopes.

CONTINUING EDUCATION

CONTINUING EDUCATION AIA

Use the following learning objectives to focus your study while reading this month's ARCHITECTURAL RECORD/ AIA Continuing Education article. To receive credit, turn to page 156 and follow the instructions. Another opportunity to receive Continuing Education credits in this issue can be found in the sponsored section beginning on page 163.

LEARNING OBJECTIVES

After reading this article, you should be able to:

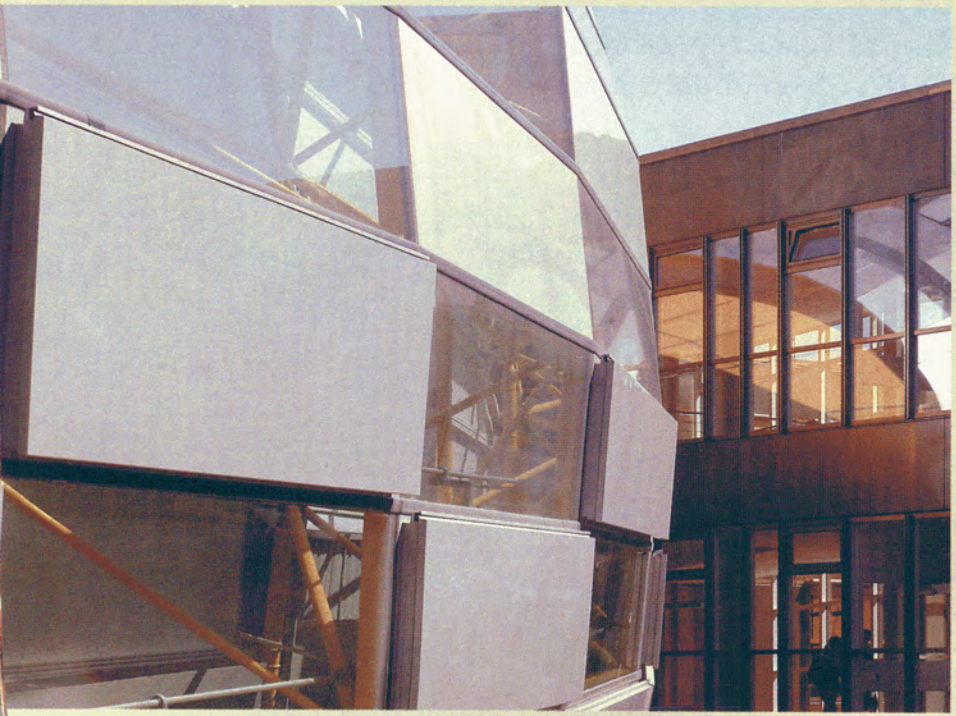
1. *Describe interactive building envelopes.*
2. *Explain the current interest in active building skins.*
3. *Identify the application most responsible for interactive building support.*

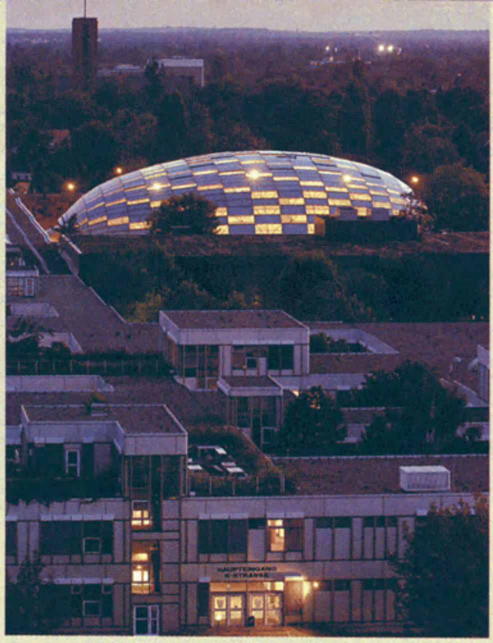
For this story and more continuing education, as well as links to sources, white papers, and products, go to **www.archrecord.com**.

Thanks largely to innovators from Europe, buildings are wearing more smarts and moving parts. The lion's share use double-skin construction as well, in which inner and outer glass walls are separated by a ventilated cavity that often contains solar shading. Hundreds of double-glass or interactive envelopes appeared in Germany and Austria in the 1990s. In the United States, such projects are novelties, despite the existence here of an early example that debuted during the early 1980s oil crisis: Cannon's Occidental Chemical Center in Buffalo, New York, introduced a double-wall facade containing automated operable louvers.

Back then, the idea was an anomaly. Today, activating the skin is in vogue, note critics and proponents alike. From the "robotecture" labs at top architecture schools to interactive art installations like James Carpenter's *Podium Light Wall* for New York's 7 World Trade Center, aesthetics and technology are converging in unlikely places. Nonetheless, the mainstream drivers for interactive envelopes are sustainability and stringent energy codes. Another is heightened interest in "Wooster"—the end user. "The costs can't be justified strictly on the basis of energy savings," points out Eleanor S. Lee, a scientist and architect in the Building Technologies Program at Lawrence Berkeley National Laboratory (LBNL), Berkeley, California. "But these systems will be used increasingly for occupant satisfaction, including thermal comfort, acoustical performance, and access to fresh air."

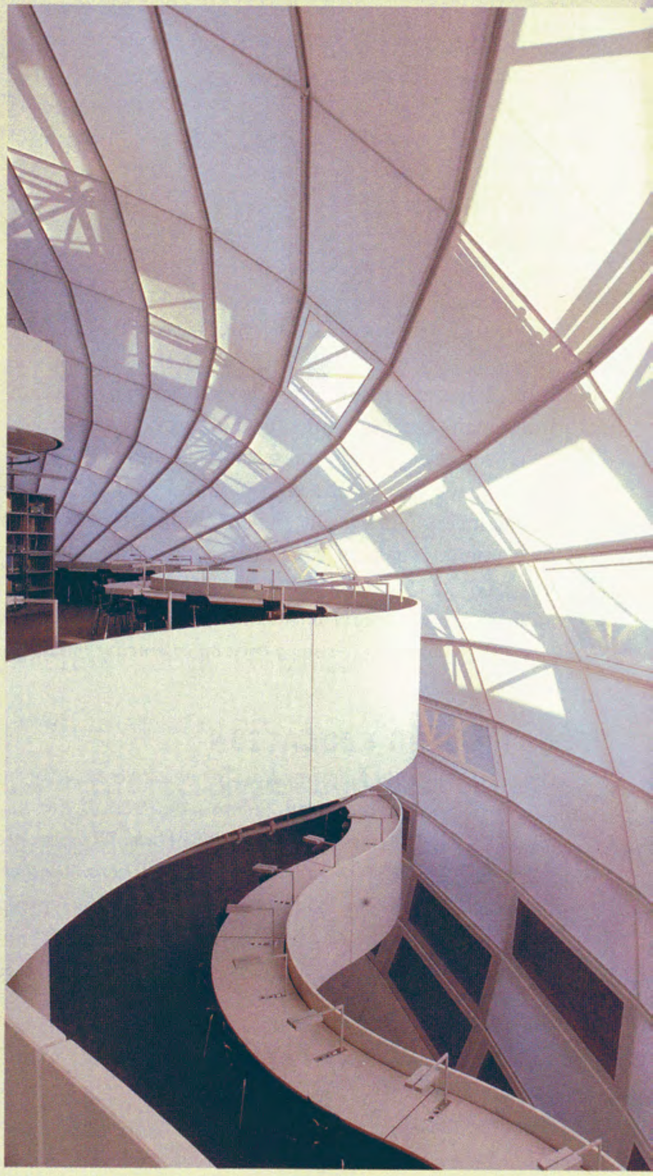
While fashionable and possibly advantageous, the adoption of high-tech envelopes has been slow. Skeptical architects worry that operable components are magnets for value-engineering. Or they foresee them being unplugged and later stripped off their buildings due to poor

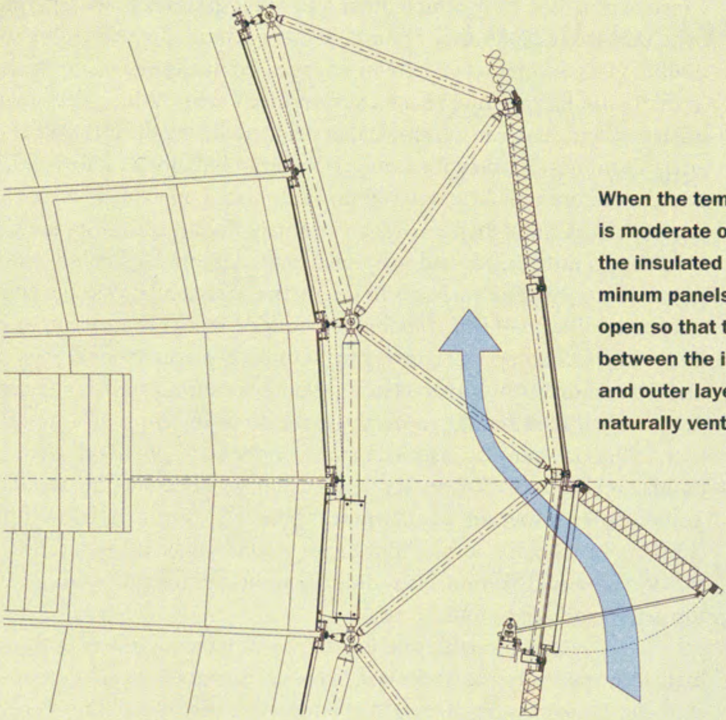




Free University Berlin

This building has an outer layer of windows and aluminum panels, and an inner layer of fiberglass fabric. In winter, warm air between the layers rises to the top, then is drawn down through the building to provide heat.





When the temperature is moderate outside, the insulated aluminum panels swing open so that the space between the inner and outer layers is naturally ventilated.

SECTION DETAIL

performance or deficient maintenance. Other firms cite client interests, noting such high-profile failures as the broken actuators on the sun-control diaphragms cladding Jean Nouvel's 1988 Institute du Monde Arabe in Paris. "Culturally, we have little confidence in what we're doing, and in systems integration for these hybrids," says Volker Hartkopf, director of the Center for Building Performance and Diagnostics at Carnegie Mellon University, Pittsburgh. "Yes, these things can break, but so can fans, dampers, thermostats, and so many other things we take for granted."

"I think such worries are well-founded," counters Bruce Nichols, a principal of the New York City–based facade consultancy Front Inc. "While an automobile maker is a single source of responsibility, that doesn't happen in architecture." He recounts his work with the Japanese firm SANAA on a competition-winning office building for the Novartis campus in Basel, Switzerland. For its transparent triple glazing with integral automated ventilation and Venetian blinds, the shades came with only five-year warranties; the glass was guaranteed for at least 10 years. So, if a shade fails after five years, Novartis would have to pay for replacing a glass unit just to access the defective shade. "We asked the manufacturers if they could get their act together to offer a collective warranty," Nichols recalls. "They couldn't."

Beyond famous failures, high installed costs, and mismatched warranties lay big coordination challenges, adds Nichols, and conflicting liabilities among project team members. Plainly, the road to the interactive envelope is a rough one. But at the end of the ride, optimal energy performance is the payoff, right? So it is hoped. Yet Lee warns there is shockingly little postoccupancy data to confirm initial design claims on older projects.

TWO THIRDS OF COMMERCIAL BUILDING COOLING LOADS COME FROM LIGHTING SYSTEMS AND SUN-LOADED GLASS SURFACES.

Sun-tracking systems lead the way

While animated as much by polemics as by actuators, new interactive envelopes still have fervent supporters. A single, conventional application gets most of the credit for the good buzz: daylighting control. On its own, an operable shade or louver is easy for an architect to analyze, especially with new daylight analysis tools built into common CAD platforms. The overarching driver for most automated shading is the typical energy profile of large commercial buildings, according to LBNL. Cooling loads dominate, with more than two thirds needed simply to counteract heat gain from lighting systems and sun-loaded glass surfaces.

Also encouraging the use of interactive envelopes is the solid performance of photosensors, dimmable lighting controls, and novel solar-tracking devices. More recent advances include switchable glazings, sometimes called "smart windows." These automatically tint or frost, activated by either an applied voltage (electrochromic) or a small release of gas, such as hydrogen (gasochromic). The former type is more widely available, but both can reduce combined cooling and lighting loads by up to 5 watts per square foot in interior perimeters.

Another appeal of automated shading relates to the feasibility of the highly transparent, relatively unarticulated building enclosures currently in fashion. For Arizona State University's Biodesign Institute in Tempe, collaborators at Gould Evans and Lord Aeck Sargent Architecture compensated for a large easterly expanse of window walls by using interior aluminum louvers controlled continuously by photocells and sun-tracking software. A manual override accessible through occupants' computers allows personal adjustments to be made.

Biodesign Institute, Arizona State University, Tempe
A large, easterly expanse of windows uses aluminum louvers that are controlled continuously by photocells and sun-tracking software. The design allows occupants to control most of the louvers in their offices using their PCs, although at above 8 feet from floor level the louvers are controlled automatically.

TIMOTHY HURSLEY (THIS PAGE, MIDDLE); MARK BOISCLAIR (THIS PAGE, TOP AND BOTTOM)

Caltrans District 7 Headquarters, Los Angeles
Different elevations of the building have different systems. On the south side (above), large photovoltaic panels form a brise-soleil. On the east and west facades, perforated solar-shading screens hang a foot from the exterior wall. When they heat, air around them rises, which draws cooler air from ground level. Each day, about 1,000 screens (above right), which are located in front of windows, open and close.

Is intelligent shading worth the bother? LBNL tests suggest so. Automated daylight setups coupled with dimmable and switchable electrical lighting beat conventional fixed blinds in terms of energy draw by about a third in winter and up to 52 percent in summer. Measured daylighting levels are comparable to those for unshaded bronze glazing, with only half the solar heat gain. Lee adds that the systems allow building managers to voluntarily curtail electrical loads as part of utility demand-response programs, which help avert blackouts.

Active doubles, anyone?

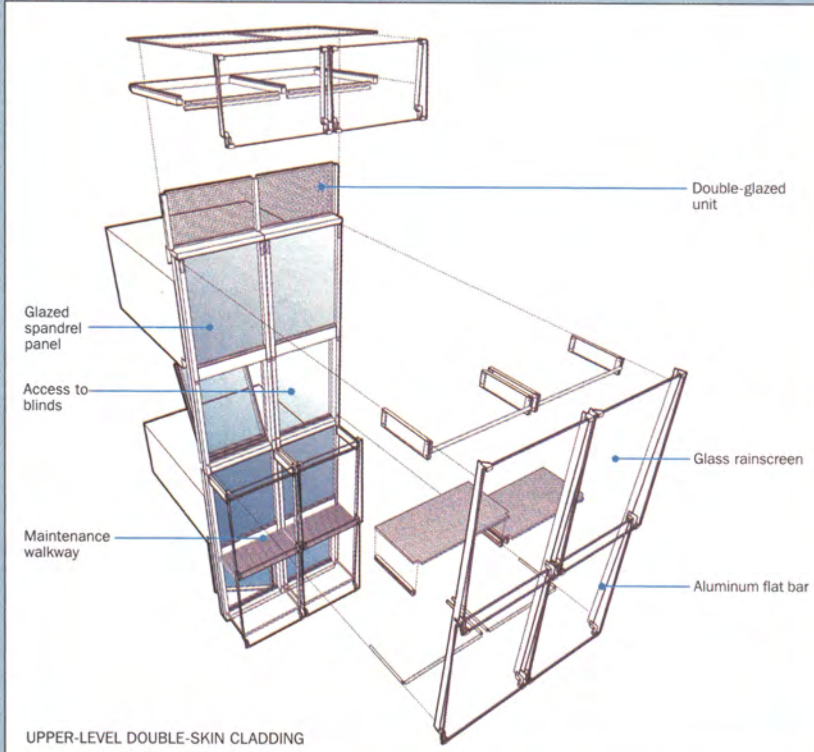
Harder to predict are the benefits of hybrid envelope systems, in which two or more interactive strategies are combined. Many European architects have integrated ventilation, shading, and other active technologies into double-wall facades that serve as primary space conditioners. Unlike Cannon's Occidental Chemical building, early double envelopes had few moving parts. (Some Europeans use the term "active facade" to describe any ventilated double wall, regardless of operability.) More recent projects feature more "edge monkeys": automated hoppers, vents, and shades.

An extreme example is the philology library by Foster and Partners at Berlin's Free University, completed last year. The four-story, orblike enclosure—with an underfloor air plenum—is engineered for free cooling for about seven months of the year using natural ventilation. A checkerboard cladding of aluminum and glazed panels protects an inner glass-fiber membrane. Operable panels close during cold weather, and fresh air is drawn from outside through the floor cavity and into the envelope void. A concrete internal structure provides thermal mass and radiant cooling and heating of recirculated air. The client expects about 35 percent energy savings over a comparable facility.

Hopefully, performance data will bear this out. But unlike Foster's 1997 energy-miser Commerzbank Tower in Frankfurt, most large-scale projects don't document utility costs. Karl Gertis, a building physics researcher at the University of Stuttgart, thinks it's because they often miss the target. In the design phase, simulations prove notoriously unpredictable, he believes. Once built, natural ventilation often isn't adequate for room air handling or for maintaining comfortable temperatures. Weak convective airflows in wall cavities may preclude the use of insect screens and air filters, too. Last, Gertis cites numerous buildings designed without mechanical cooling that have failed. Foster's library stands prepared: On hot days, it leeches supplemental cooling from an adjacent structure.

For Plantation Place, a large office development in London, Arup Associates incorporated active solar shading and occupant-controlled operable ventilation in its double-skinned cladding design. At their lower levels, the buildings have a heavy curtain of limestone fins in deference to the masonry expression of the project's Neoclassical neigh-

PHOTOGRAPHY: © ROLAND HALBE



Aurora Place, London
At the upper levels of the building, the outer layer of double-skinned facade is made up of frameless glass panels, angled at 3 degrees, with open joints. Behind the screen is a walkway used for maintenance. Tenants can open the windows to provide natural cooling. The window blinds are automatically raised or lowered based on current conditions in each tenant zone. The blinds are accessible from the outside for cleaning and maintenance.

bors. Upper levels, on the other hand, are all glass, yet those floors can be cooled with only natural ventilation during much of the year. The outer layer of the 2-foot-deep double walls comprises a rain-and-wind screen of shingled, frameless glass panels, angled at 3 degrees, with open joints. Behind it is a maintenance walkway and solar blinds adjacent to an inner window wall with operable panels. The two layers were delivered to the job site as 5-foot modules and prefabricated on-site into units with integral blinds and catwalks.

To ensure that occupants enjoyed the benefits of the complex facades, Arup Associates and facade engineers from Arup planned an unusual daylighting scheme. In each tenant zone, photosensors were mounted on inner facades to automatically control the raising and lowering of blinds based on local conditions. "There are reliability questions for automated daylighting control," admits Arup facade engineer Neil McClelland. "Any design should recognize that there will be issues and allow for access to the blinds for cleaning and maintenance." McClelland adds that the main reason to use automated blind controls is for maximum transparency, not energy-efficiency.

Stick-built robotics

For many architects, the European tradition of customizing an off-the-shelf, unitized, double-wall product presents a safe and effective entrée into the world of interactive facades. Less prevalent is the craft-based approach used by Thom Mayne for Caltrans District 7 Headquarters in Los Angeles, which opened in late 2004. There, Morphosis Architects pulled apart the envelope's functional elements, "redelegated" them, and coordinated their job-site "reassembly" among seven exterior subcontractors, says project leader Pavel Getov.

The result combines a large photovoltaic array and independently controlled, automated elements within a multiple-layer facade. The prominent shading layer of perforated metallic panels on east and west facades cuts initial solar heat gain by about 15 percent. The screen hangs about 1 foot from the slab edges of a weather-wall of metal framing, gypsum sheathing, and PVC membrane. In this way, the intervening space functions partly as convective cavity. One thousand or so of the scrim panels, corresponding to ribbon windows behind, open or close daily. Those on the east close in the morning, those on the west in the afternoon. For longevity, the architects specified stainless-steel hardware and a single pneumatic lift per panel, rather than the pair of electrical actuators originally considered. A rooftop sensor signals the panels to close during high winds.

According to Getov, 3D modeling and mock-up testing ensured the performance of the stick-built envelope under wind, rain, and seismic conditions. The firm shared a single building-information model among consultants and manufacturers, and component prototypes made on a 3D printer. Still, says Getov, "A lot of the design is resolved through the mock-ups." Even with extensive reviews and site visits for the customized, kinetic countenance, the project penciled out at $165 per square foot, including finished interiors and design fees—about the same as an average office building. The building's small facade area in relation to its floor plate accounts in part for the cost-effectiveness. Energy savings are projected at about 40 percent. Getov's advice for architects interested in the process seems counterintuitive. "The small manufacturers can be the most helpful because they don't already have a set solution in place," affording architects more conceptual control and collaboration, he explains. "It allows you to break down the process."

Omniscient control, or edge monkeys?

Beyond two ways to build a wall, the Morphosis projects also suggest two ways to make walls smart: independent control or centralized control. A project at Cooper Union in New York will integrate all facade operations into the building automation system (BAS), whereas Caltrans has independent (although Internet-accessible) envelope controls and a common override function only for emergencies, such as high winds.

Recent thinking on active envelopes mirrors that for m/e/p design generally: avoid complexity and, therefore, very integrated schemes. Some projects, such as Arup's Plantation Place , have explored highly localized automation. There, sensors mounted on the inner facade detect solar conditions for each tenant zone. Solar blinds in specified areas raise or lower autonomously, depending on the local temperature, sun strike, and occupant preferences. Natural ventilation rates are determined locally as well. Like the robotic edge monkeys, however, such islands of control need occasional global guidance—and the will to ignore the people they serve. "You can't rely on human input," says Arfon Davies, an associate with Arup Lighting in London. "And if automatic shading controls are independent from the BAS, they should still be able to send a signal to the BAS to indicate a fault."

Davies adds that even the most automated systems should have a local override. More important, says LBNL's Lee, "Windows are very much a personal item, and having that control taken away from you can be a pain. You have to have manual override." Taking a related tack, Gould Evans chose to split the control of interior blinds for Biodesign Institute. Above 8 feet from each floor, the shading is fully automated based on solar position; below that, occupants choose. "These systems begin to have a determinist impact on the psychology of the user," says Gould Evans principal Jay Silverberg. Is any optimism warranted for a new wave of smart buildings? "Architectural environments will be increasingly smart and responsive and capable of complex behaviors," predicts Michael Fox, the Venice, California–based architect and robotics expert. "Designing interactive architectural systems is not inventing, but appreciating and marshaling the technology that exists and extrapolating it to suit an architectural vision."

Edge monkeys, indeed. ■

AIA/ARCHITECTURAL RECORD CONTINUING EDUCATION

INSTRUCTIONS

- Read the article "Robo Buildings: Pursuing the Interactive Envelope" using the learning objectives provided.
- Complete the questions below, then fill in your answers (page 204).
- Fill out and submit the AIA/CES education reporting form (page 204) or download the form at www.archrecord.com to receive one AIA learning unit.

QUESTIONS

1. Where did double-glass or interactive-envelope buildings first appear in the early 1980s?
a. Germany
b. Austria
c. England
d. New York

2. The driving forces for interactive envelopes are all except which?
a. occupant satisfaction
b. sustainability
c. value engineering
d. stringent energy codes

3. The conventional application responsible for the fervent support of interactive envelopes by designers is which?
a. fresh-air ventilation
b. daylighting control
c. thermal-mass cooling
d. radiant cooling

4. Adoption of high-tech envelopes has been slow because architects worry about which?
a. operable components being stripped off buildings
b. stringent energy codes
c. sustainability
d. the novelty of the idea

5. The drawbacks to using interactive envelopes include all except which?
a. high installed costs
b. mismatched warranties
c. occupant satisfaction
d. famous failures

6. The typical energy profile of large commercial buildings shows what amount of the cooling load is needed to counteract the heat gain from lighting and sun?
a. one fourth
b. one third
c. one half
d. two thirds

7. Smart windows consist of which?
a. photosensors
b. dimmable lighting controls
c. switchable glazings
d. solar-tracking devices

8. The energy draw of conventional fixed blinds is beat by up to 52 percent in summer by which?
a. automated daylight setups
b. dimmable electric lighting
c. switchable electric lighting
d. a combination of all three

9. The European use of the term "active facade" describes which?
a. primary space conditioners
b. any ventilated double wall
c. edge monkeys
d. hoppers, vents, and shades

10. According to Morphosis's Pavel Getov, small manufacturers can be the most helpful to architects contemplating the robotics process for which reason?
a. they will cost less
b. they have more experience
c. they do not have a set method in place
d. they will exert more control